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Technical Report
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# Abstract

The use of Extremely Agile Micro Aerial Vehicles (EA-MAVs) drives the need for a small and light controller which will not hinder a soldier carrying it. This requirement brings an issue of designing an effective operator interface coupled with the controller. Little human factors work has been done on what the most effective method is for controlling EA-MAVs using a handheld device. To investigate design methods for the development of an interface which must be intuitive in function and easy to learn for an average soldier, DRDC Toronto conducted an experiment to evaluate interface display mode and command control input method. Display mode compared a display that showed both a sensor view and a map view (simultaneous) with a display that showed one view at a time (sequential). Command control input method compared two types of input control methods: touch screen and tactile buttons. Forty four (44) subjects participated in the experiment and navigated a virtual EA-MAV through specified waypoints in an urban area and a building. Subjects' performance was measured against six dependent variables: (1) situation awareness, (2) display switch frequency (between sensor view and map view), (3) task completion time, (4) mental workload, (5) trajectory error of the flight, and (6) training time. The results revealed that the simultaneous display and the touch screen control are the optimal design methods for the handheld interface to be used easily when maintaining situation awareness. The findings provided guidance for designing operator interfaces on handheld devices and further facilitated the development of a statement of requirements of EA-MAV systems.

# Résumé

L’utilisation des Extrêmement agile Micro Aerial Vehicles (EA-MAV) entraîne la nécessité d’un contrôleur petit et léger à apporter qui ne réduira pas la performance du soldat. Cette condition a amené à concevoir un interface opérateur couplé avec le contrôleur. Une recherche de facteurs humains qui était effectué sur la méthode la plus efficace, est développé pour contrôler EA-MAVs en utilisant un dispositif portable. Pour investiguer le design des méthodes en développement d’un interface qui doit être intuitif dans la fonction et facile à apprendre pour un soldat moyen, RDDC Toronto a entrepris une expérience pour évaluer l'efficacité du mode d’affichage et la méthode du commande de contrôle d'entrée. Le mode d’affichage a comparé un affichage qui combine une vue due capteur et une vue de carte (simultanée), avec un affichage qui sépare les deux points de vue (séquentiel). La méthode du commande de contrôle d'entrée a comparé deux types de méthodes de contrôle d'entrée: écran tactile et des boutons tactiles. Quarante-quatre (44) sujets ont participé à l'expérience et ont navigué une EA-MAV virtuelle en passant par des points-route spécifiques, dans une zone urbaine et un bâtiment. La performance des sujets était mesuré par rapport à six variables dépendantes. (1) conscience de la situation (2) affichage de la fréquence de commutation (entre la vue de capteur et de carte), (3) le temps l'exécution des tâches, (4) charge de travail mental, (5) erreur de trajectoire du vol, et (6) le temps de formation. L'expérience a révélé que l'affichage simultané et l'écran tactile de contrôle sont les méthodes de conception les plus optimal pour soit utiliser facilement que l’interface portable et facile pour un utilisation facile en maintenant la conscience de situation. Ces résultats fournissent un guide pour la conception d'interface d’operateur dans dispositifs portables et ont facilité le développement des conditions des systèmes d’ EA-MAV.

# Executive summary

## An Empirical Study on Operator Interface Design for Handheld Devices to Control Micro Aerial Vehicles:

**Ming Hou; Sheila Young; Shi Yin; Joshua Ru Selvadurai DRDC Toronto TR 2010-075; Defence R&D Canada – Toronto; October 2010.**

Extremely Agile Micro Aerial Vehicles (EA-MAVs) are miniature flying machines that will provide “over-the-hill” or “around-the-next-house” reconnaissance to smaller combat elements such as infantry sections. This system is expected to be used by the Canadian Forces (CF) to improve local situation awareness (SA) in an urban setting. To better use such technology, soldiers will require a suitable Ground Control System (GCS) to interface with the flying device they are operating. Although a number of handheld devices have been developed to serve as a GCS for the control of EA-MAVs, there is no operator interface design guidance for a GCS on a handheld device. Consequently, there is a requirement for Human Factors research to be carried out to investigate an optimal interface design method for the control of EA-MAVs using a handheld device. A previous focus group study has looked into general system operational requirements and desired interface features. The study results suggested a further investigation on interface display mode and command control input method as they are directly related to the control of the EA-MAV system and maintaining of SA. Thus, the objective of this research is to explore an optimal display mode and a command control input method.

Forty four (44) subjects participated in an experiment using a handheld GCS to navigate a virtual EA-MAV through specified waypoints in an urban area and a building. Interface display mode and command control input method were evaluated on subjects’ performance. Display mode compared a display that had a sensor view and a map view side by side (simultaneous) with a display that showed one view once at a time (sequential). Command control input method compared two types of input control methods: touch screen and tactile buttons. Subjects’ performance was measured against six dependent variables: (1) situation awareness, (2) display switch frequency (between sensor view and map view), (3) task completion time, (4) mental workload, (5) trajectory error of the flight, and (6) training time.

The results revealed that the display mode and control type affected EA-MAV operations. The simultaneous display provided better situation awareness and produced lower display switch frequency than the sequential display. Touch screen control resulted in a faster task completion time than the tactile button control. Participants reported lower mental workload with the touch screen control than with the tactile button control. These findings can be used as development recommendations for a statement of requirements and interface design guidance for general EA-MAV systems. For better situation awareness the interface should be able to display both sensor view and map view simultaneously. For the ease-of-control, a handheld device with a touch screen is preferable over a device with tactile buttons.

# Sommaire

## Une Etude Empirique sur la Conception d’un Interface Opérateur dans les dispositifs portables pour contrôler les Micro-drones (MAV):

**Ming Hou; Sheila Young; Shi Yin; Joshua Ru Selvadurai DRDC Toronto TR 2010-075; R & D pour la défense Canada – Toronto; Mai 2010.**

Pour une meilleure utilisation d’une telle technologie, les soldats ont besoin d’un système de contrôle au sol (GCS) approprié pour communiquer avec le dispositif de vol. Bien que un nombre des dispositifs portables ont été développés pour servir comme un GCS pour le contrôle d’EA-MAVs, il n’y a aucune conception d'un guide d’interface d’opérateur pour un GCS, sur un dispositif portable. Par conséquent, il y a une exigence d’une recherche des Facteurs Humains à mettre en œuvre pour réaliser une interface utilisateur le plus efficace pour le contrôle de EA-MAV en utilisant un dispositif portable. Une étude précédente a examiné les conditions opérationnelles du système général et les caractéristiques des dispositifs désirés. D’après les résultats d'étude, une recherche plus approfondies sur l’interface du mode d’affichage et la commande de contrôle d'entrée est nécessaire comme ils sont directement liés au contrôle du système d'EA-MAV et au maintenance du SA. Ainsi, l'objectif de cette recherche est d'explorer une méthode optimal du mode d'affichage et commande de contrôle d'entrée.

Quarante-quatre (44) sujets ont participé à une expérience en utilisant un GCS portable pour naviger une EA-MAV virtuelle en passant par des points-route spécifiques, dans une zone urbaine et un bâtiment. L’interface du mode d’affichage et la méthode du commande de contrôle d’entrée ont été évalués à partir de la performance des sujets. Le mode d’affichage a comparé un affichage qui combine une vue de capteur et une vue de carte (simultanée), avec un affichage qui sépare les deux points de vue (séquentiel). La méthode du commande de contrôle d’entrée a comparé a comparé deux types de méthodes de contrôle d'entrée: écran tactile et des boutons tactiles. La performance des sujets était mesuré par rapport à six variables dépendantes. (1) conscience de la situation (2) affichage de la fréquence de commutation (entre la vue de capteur et de carte), (3) le temps l'exécution des tâches, (4) charge de travail mental, (5) erreur de trajectoire du vol, et (6) le temps de formation.

L'expérience révèle que le mode d'affichage et le type de contrôle ont des effets sur le fonctionnement des opérations d’un EA-MAV. Affichage simultané fournit une conscience de la situation plus élevés et une fréquence commutateur d'affichage plus bas, par rapport à l'affichage séquentiel. Contrôle d’écran tactile montre un délai d'exécution des tâches plus rapidement que le contrôle de bouton tactile. Les participants ont signalé une baisse de la charge mentale avec l'écran tactile qu'avec le contrôle bouton tactile. Ces résultats fournissent des orientations pour la conception d'interface utilisateur pour les systèmes générales d’ EA-MAV. Pour avoir une meilleure conscience de situation, l'interface doit être capable d’afficher une vue de capteur et une vue de carte simultanément. Pour le facilite-de contrôle, un dispositif portable avec un écran tactile est plus préférable qu’un dispositif avec des boutons tactiles.

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# 1 Introduction

Micro Aerial Vehicles (MAVs) are miniature flying machines that will provide “over-the-hill” or “around-the-next-house” reconnaissance to smaller combat elements such as infantry sections. The Extremely Agile Micro Aerial Vehicle (EA-MAV) currently under development by DRDC is an electric, fixed-wing aircraft equipped with a video sensor and an audio sensor (Ste-Croix & Angel, 2008). The forward flight speed of this MAV varies from a standstill to a running pace. In the hovering mode with the nose pointed vertically up, it can roll about its longitudinal axis to scan its surroundings with the video sensor. Using onboard electronics, the MAV automatically stabilizes its altitude. While it is recoverable, depending on the tactical situation, the soldier may discard this MAV due to its low cost.

To better use this technology, soldiers will require a suitable Ground Control System (GCS) to interface with the flying device they are operating. The GCS must be subject to stringent engineering criteria, such as the robustness to withstand extreme heat, moisture and acceleration. The GCS must also be small and light enough to not seriously hinder the soldier who carries it. To interact and control a MAV through the GCS, the soldier requires a graphic user interface (GUI) embedded within the GCS. This GUI should be subject to stringent Human Factors (HF) engineering design criteria, such as the amount of sensory data displayed, screen size, resolution, and optimized map and video sensor views, etc. It must be easy to learn for the average soldier, and must be intuitive in functionality and display so that quick responses can be achieved during mission critical moments in deciphering what the next control sequence should be.

A number of handheld devices have been developed for Uninhabited Vehicles (UVs) and robots. These include Personal Digital Assistants (PDAs) (Fong, Thorpe, & Glass, 2003; Huttenrauch & Norman, 2001; Miller, et al., 2003), portable tablet laptops (Rutley, 2005), and modular systems (Quigley, Goodrich, & Beard, 2004; Murphy, Wu, & Miller, 2007). Handheld devices may either serve in a larger GCS as a component of the operator interface or video interface, or they can function as the integrated GCS. However, higher automation in UVs may impair situation awareness (SA) and lead to accidents (Parasuraman & Miller, 2006; Miller & Parasuraman, 2007). Despite developed design principles for PC-based UV interfaces (Hou & Kobierski, 2006; Hou, Kobierski, & Brown, 2007; Hou, Kobierski, & Herdman, 2006), insufficient HF work is available to determine the most appropriate hardware platform and the most effective interface design method for controlling a MAV using a handheld device.

To address the lack of HF research on desirable interface design approach for a handheld device to control a MAV, Defence Research and Development of Canada (DRDC) – Toronto conducted a HF study on the design principles, implementation, and evaluation of GUIs on different types of handheld input devices and interface design approaches. General usability heuristics were used in this study. Research components in this study included several tasks: 1) development of concept of operations (CONOPS) for a MAV; 2) development of a draft Statement of Requirements (SOR) of a MAV system; 3) a focus group validation study of SOR; 4) development of prototype GUIs; 5) evaluation of prototype GUIs; and 6) recommendations on GUI design principles.

With the developments of CONOPS and draft SOR, identified characteristics include: GCS physical aspects, MAV stowage and maintenance, desired MAV performance characteristics, and desired GUI features and functions (Ste-Croix & Angel, 2008). The SOR set forth usage guidelines for the GCS and GUI, but indicated that there were many unanswered questions regarding the ideal platform and interactions to support in-theatre MAV use. The MAV needs to be small enough to carry in a backpack and inexpensive enough to leave behind if damaged. A lighter and smaller sized aircraft and GCS will result in higher mobility of the soldier carrying the equipment. A particular challenge was the ability to fly through a window or doorway to provide intelligence regarding a building's contents. The focus group study showed that gaming-style controllers (Xbox 360) lead to faster training and easier operation in the field. Within this category of control system devices, two other types of GUIs were developed on Sony's PlayStation Portable (PSP) and Nokia Internet Tablet (Haylock, 2008, Hou, et al., 2009). Due to the incompatibility of the PSP with Adobe Flash™ software (version 10), an Ultra Mobile Personal Computer (UMPC) Viliv S5 was identified and used to develop GUIs and evaluate interface design concepts. The Viliv S5 is portable and compact, and a 5-inch (diagonal) touch screen. It also has tactile buttons and a mouse for control input.

An unanswered question from the focus group study was what display mode of a GUI can give an operator better SA given the limited screen size of a handheld device. Would the operator get better SA with a simultaneous display having both senor and map views than with a sequential display having one view at a time to use the maximum screen size? Another unanswered question from the focus group study is what command control input method is more effective to control a MAV? Would it be more effective to input control command through touch screen than through tactile buttons of the handheld device?

Since these two questions are directly related to the effective control of the MAV and maintaining SA for the operator, an empirical study was planned and performed to address these questions as the first step of the development of interface design guidelines. This report describes the methodology, the design and implementation, the experimentation, and the research results. The findings provide a starting point in understanding how an operator interface on a hand held device can be designed for effectively controlling a MAV system. The implications of this study contribute to the development of SOR for MAV systems.

# 2 Experiment Platform

## 2.1 Apparatus

The experiment platform was developed in a number of phases, including requirement analysis, system design, implementation, and quality assurance. A complete experimental system consisted of two standard IBM Personal Computer (PC), two 17” LCD monitors, two standard US-105 Key IBM keyboards, two standard USB optical IBM mouse, a Viliv S5 Ultra Mobile Personal Computer (UMPC) with a screen size of 10.5cm x 6.3cm and a screen resolution of 1024 x 600 pixels, and a Linksys WRT54GL wireless router to connect the two computers, as shown in Figure 1. Both computers used the Windows XP Professional 2002 operating system displayed on a LCD monitor with screen dimensions 41 cm x 31 cm and a resolution 1280 x 1024 pixels resolution with the participant seated approximately 55 cm away from the monitor. The virtual MAV, the virtual environment, and the user interface were implemented using Adobe Flash™, LUA Code, and Virtual Navigation and Collaboration Experimentation Platform (VNCEP) (Perlin, 2008). The experimental data collection and pre-process mechanisms were implemented using Visual Basic and C# programming languages.

*Figure 1: The Experimental Setup*

The system and GCS were designed and developed to simulate a real world environment including control methods and sensory data display. For example, the sensory update frequency was 3-4 Hz on the experimental setup, which is a latency value that has been demonstrated not to produce any adverse effects on the controllability of the UV (Billings & Durlach, 2008). Either a ‘GO’ or ‘STOP’ button was displayed on the screen at any given time in Manual flight mode to avoid any unnecessary clutter on the graphical user interface (GUI). Another feature was seen in autopilot mode; while in flight, the altitude of the MAV was set to automatically fly the vehicle above the buildings within the virtual environment.

The GUI was developed using Adobe Flash™ version 10. A client and server architecture (Figure 2) was employed. The client ran the developed GUI on the Viliv S5 handheld GCS. The server consisted of a virtual MAV environment and corresponding experiment administration features. These features can monitor the mission and pause the mission or stop the user control at any time.

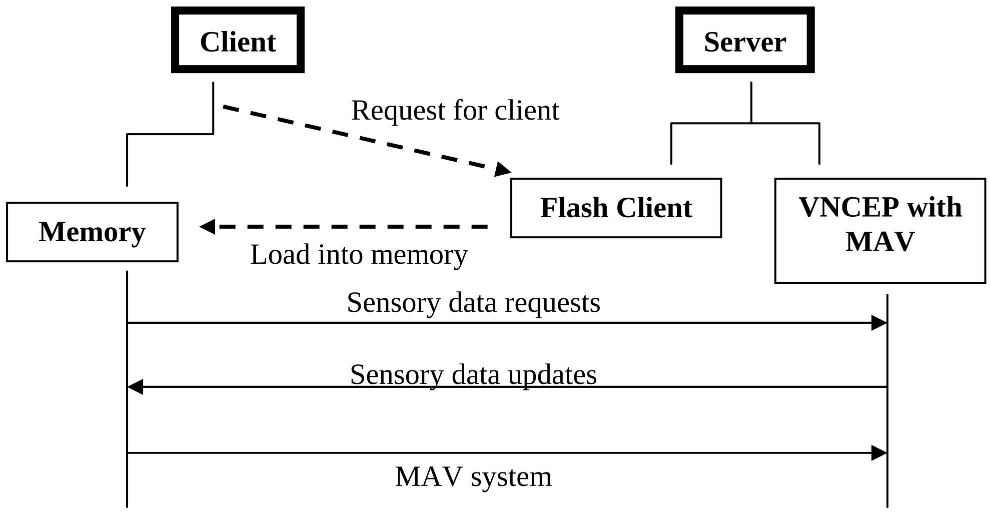


*Figure 2: Client-Server Architecture*

*The following views were incorporated into the interface for the control of a MAV: System Status, Sensor, and Map. Each view provided different essential capabilities for the operator to control and/or monitor the MAV. The Viliv S5 handheld device was chosen for this study due to its portability and compactness. The device has a 5-inch screen in diagonal.*

Figure 3 shows the System Status view. The System Status includes the status of the GPS sensor, the Communication Link, and the MAV Battery at the time of connection between GCS and the MAV. A green check mark represents proper working order. The actual GUI in the Sensor and Map view is different with respect to two different display modes described in detail in Section 2.2.

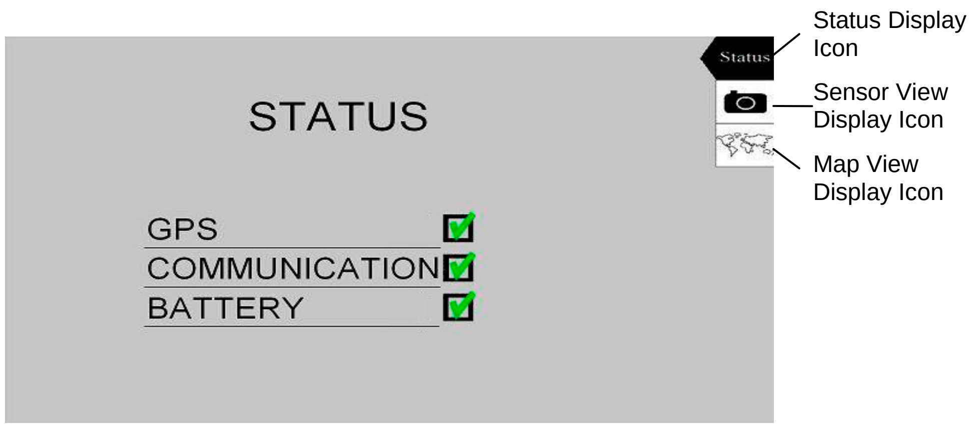


*Figure 3: System view displaying MAV Status View with interface features*

Figure 4 shows an example GUI with a simultaneous display of the MAV at the starting position. The left side of the screen shows the map view of the virtual environment, and the top right side of the screen shows the sensor view. The display controls are at the top right corner of the screen. Clicking on the Status, Sensor or Map View icons allows the user to view the respective displays. Under the icons are the MAV directional controls. ALT is the Altitude meter which gives the user the ability to adjust the altitude of the MAV by clicking along the meter during the mission. HDG is the Heading dial which allows the user to rotate the MAV by clicking an angle within the dial to adjust its heading direction. The flight modes are featured at the bottom right corner of the screen, where the MAV flies automatically through designated waypoints during Auto mode and at the command of the user during Manual mode.


*Figure 4: Simultaneous Display Mode shown on the Viliv S5 UMPC*

Other buttons on the screen include Reset, shown in Figure 6, which resets the mission when pressed and Create Route shown in Figure 8, which allows the user to designate waypoints for the MAV to fly through.

## 2.2 The Display Modes and Features

Two display modes were used in the experiment: sequential display mode and simultaneous display mode. Both of these displays included an Auto mode and a Manual mode. Auto mode allowed the vehicle to fly automatically through the set waypoints and Manual mode allowed the operator to manually control its flight path. The map and sensor views in both display modes are shown in Figure 5 through Figure 10. Figure 5 shows the sensor view in Manual, sequential display mode. The interface features include Up, Down, Left and Right directional control buttons which allow for precise adjustment of the MAV's position. Zoom In and Zoom Out buttons allow the users to focus the sensor view.

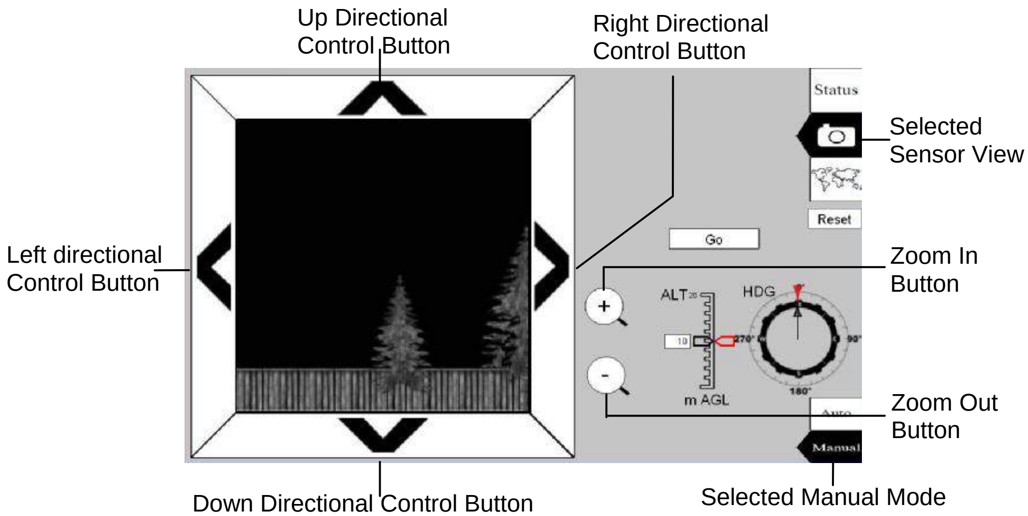


*Figure 5: Sensor View in Manual, Sequential Display Mode with interface features*

Figure 6 shows the map view in Manual, sequential display mode. The Go Button enabled the MAV to fly straight at a constant speed, and the Reset button restarts the mission if failed. The user was able to designate waypoints in the Auto mode either by touching or clicking on the desired locations, as shown in Figure 7. Here, the waypoints are indicated with green (first waypoint), blue, and red (last waypoint) crosses. The right side features a Save Route button, which allows the user to save the created waypoints. An Undo Button allows the user to delete the last waypoint created. A Stop and Clear Button allows to clear all the waypoints created. Figure 8 shows the interface after setting the waypoints and saving them. The Start Mission button commences the flight of the MAV through the trajectory path represented by the red lines.

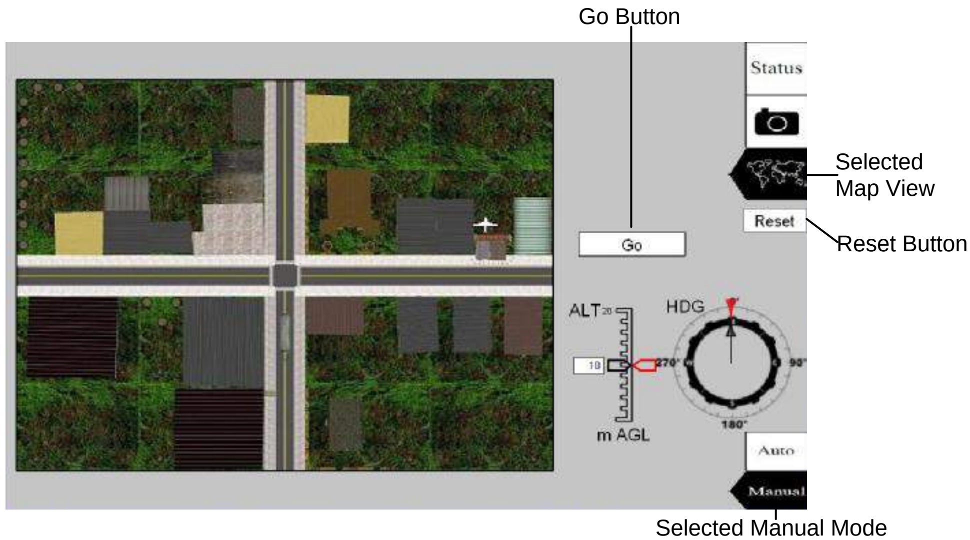


*Figure 6: Map View in Manual, Sequential Display Mode with Interface Features*

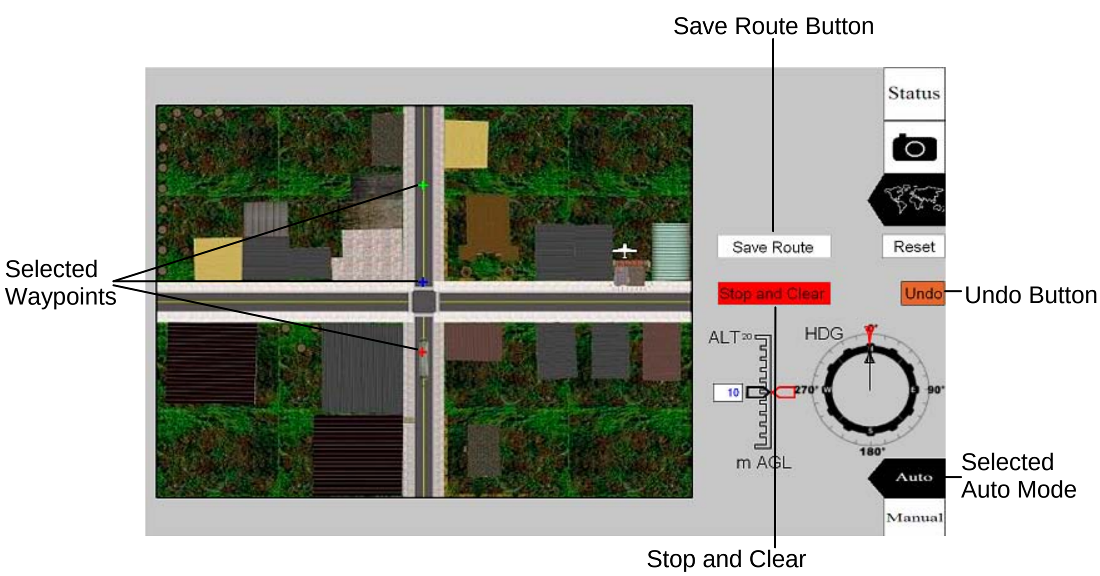


*Figure 7: Map View in Auto, Sequential Display Mode with Interface Features*

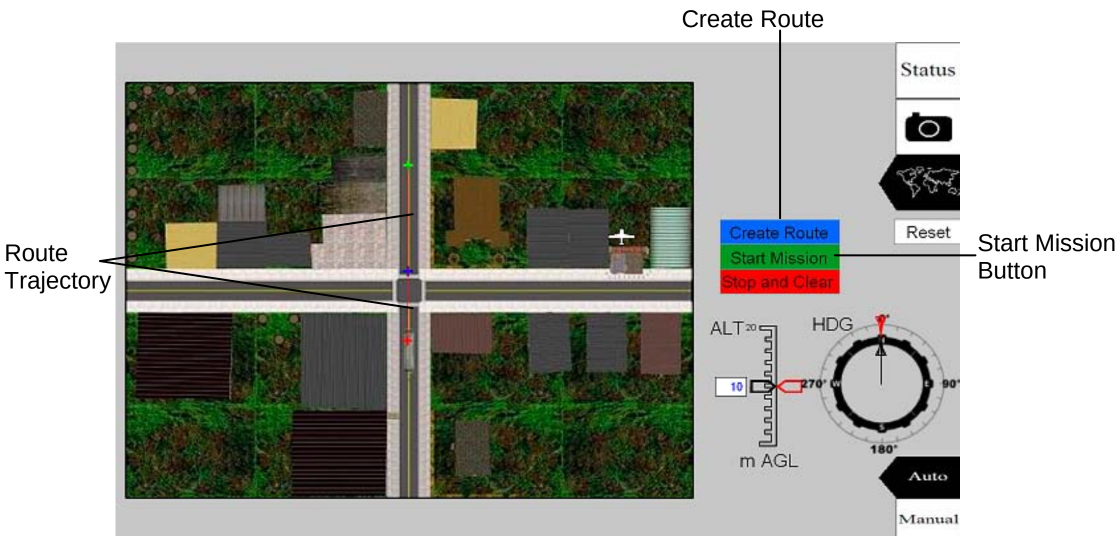


*Figure 8: Map View in Auto, Sequential Display Mode with Interface Features*

The sensor view in Manual, simultaneous display mode (Figure 9) contains the same features as Figure 5, except for the added map view on the top right side of the interface.

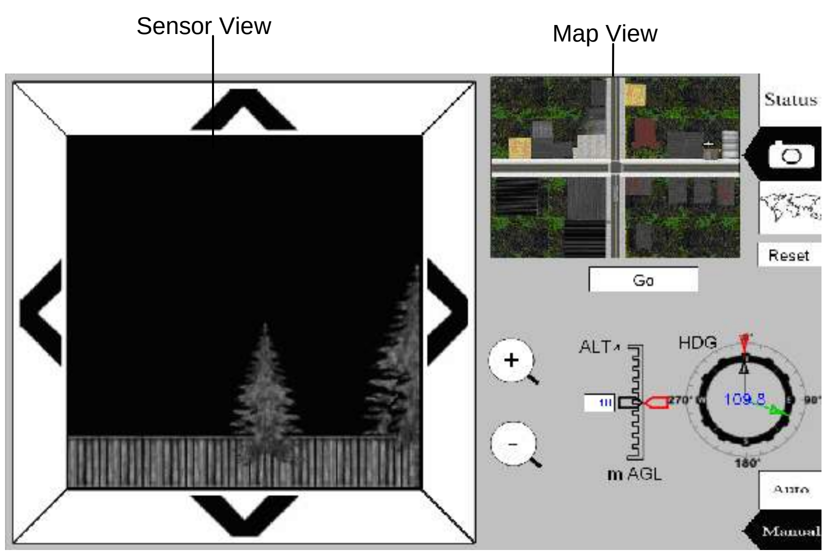


*Figure 9: Sensor View in Manual, Simultaneous Display Mode with Interface Features*

Figure 10 depicts the Map view in Manual, simultaneous display mode, which contains the same features as Figure 6 through Figure 8 but with an added sensor view on the top right side of the interface.

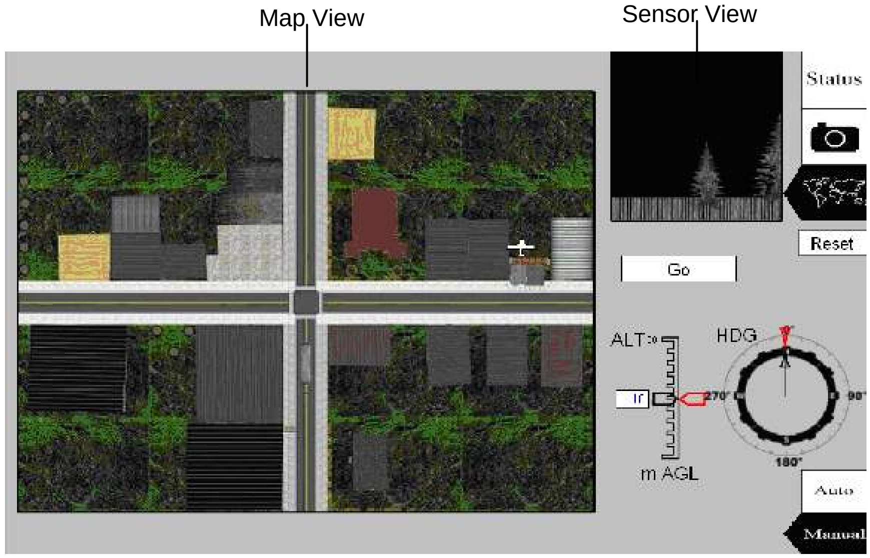


*Figure 10: Map View in Manual, Simultaneous Display Mode*

From the above figures, it can be seen that the simultaneous display mode was designed in a picture-in-picture style. The map view of the simultaneous display mode features the map as a large image, while the sensor is displayed as a small image, and vice versa for the sensor view.

## 2.3 The Control Input Type

Two command control input types were used in the experiment: touch screen and tactile buttons, as shown in Figure 11 and Figure 12 below. The touch screen control requires that the user uses a stylus to point and click on a button on the screen, as shown in Figure 11 right. The tactile button control requires that the user navigates the cursor with the mouse stick and select by pressing the OK button (left click), as shown in Figure 11 left and Figure 12.

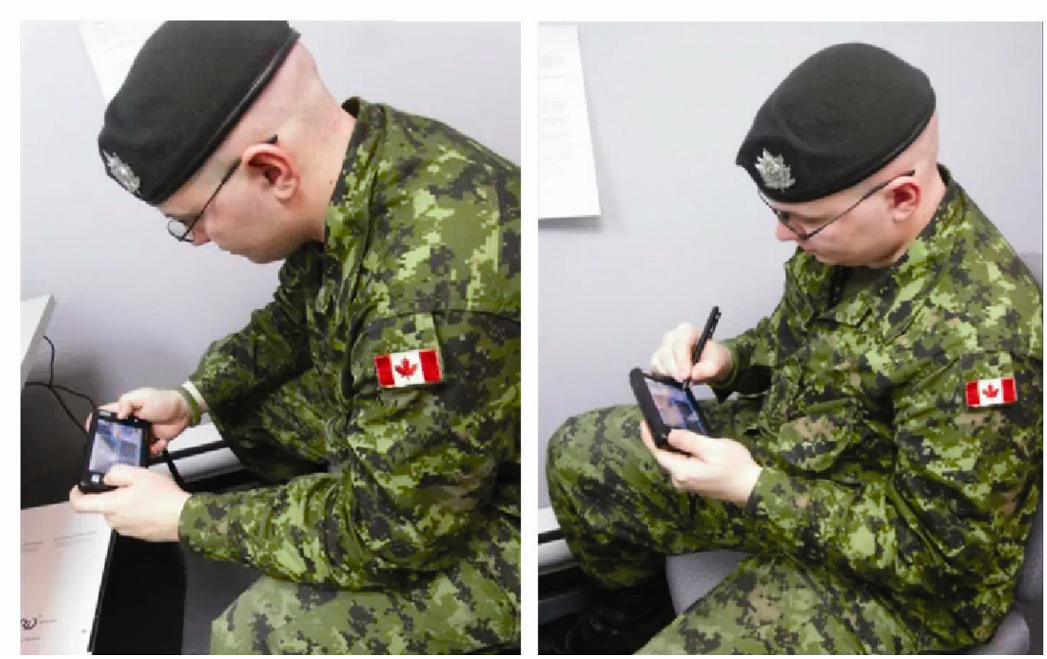

*Figure 11: The Tactile Button Control (left) and the Touch Screen Control (right)*


*Figure 12: The Tactile Button Controls*

# 3 Experimental Design

To determine effective handheld GUI display mode and device input methods, a 2 x 2 factorial and within subjects design was used in the experiment. The experiment also looked into correlation between PC and handheld device when they were used for training as well as their effects on all six dependent variables.

## 3.1 Participants

Forty four (44) volunteers from DRDC Toronto and the surrounding community were recruited by email to participate in the experiment. They were aged 18-65 (M=28.16, SD=7.24), with normal or corrected-to-normal vision. None of them had experience controlling a MAV before. Participants were to fill out a background questionnaire (Annex D) and were financially compensated for stress allowance.

## 3.2 Independent Variables

The effectiveness of the GUI interface design on aiding operators' performance was examined using a 2 (display mode condition: simultaneous view versus sequential view) x 2 (control input type: touch screen versus tactile button) repeated measures in design. There were two trials for each of the four experimental conditions created by factorially crossing these two variables. The experiment conditions are shown in Table 1, where touch screen is represented by To, tactile button is represented by Ta, simultaneous display is represented by Si, and sequential display is represented by Se.

*Table 1: Experimental conditions for MAV study.*

| | **Touch Screen (To)** | **Tactile Button (Ta)** |
|---|---|---|
| **Simultaneous (Si)** | Trial To-Si | Trial Ta-Si |
| **Sequential (Se)** | Trial To-Se | Trial Ta-Se |

## 3.3 Dependent Variables

Both objective and subject measures were used to index each participant's performance under two display modes and two control input types. There are five objective measures for the experiment: (1) trajectory error of the flight; (2) task completion time; (3) situation awareness using situation awareness global assessment technique (SAGAT); (4) display switch frequency (between sensor view and map view); and (5) training time. There was only one subjective measure which is (6) mental workload using the NASA TLX.

### 3.3.1 Trajectory Error

Trajectory error to each defined waypoint (see Figure 13) was measured using the closest distance of the MAV trajectory from that waypoint. Waypoints 1, 2, and 3 in Figure 13 were recorded only in 2 dimensions (X and Y co-ordinates) as a specific altitude (Z co-ordinate) of flight was not required for these waypoints. Waypoints A and E which are building access and exit windows were recorded in 3D (X, Y, and Z co-ordinates) as all the experiment required the windows be traversed in the center including a specific altitude. The trajectory error of a trial is calculated as the average trajectory error over all the 5 waypoints.

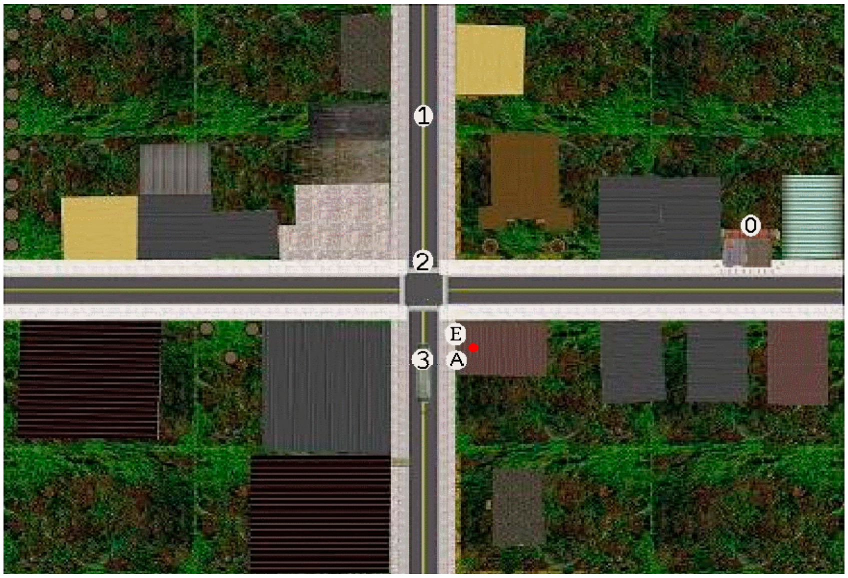


*Figure 13: Map with defined waypoints (red dot represents NPTC in room)*

### 3.3.2 Task Completion Time

The time recorded from the start (waypoint 0 in Figure 13) to the end of the mission (waypoint E) was the completion time. Due to the fact that both Auto and Manual modes were used within a single mission, the task completion time included the time used in both modes.

### 3.3.3 Situation Awareness

Situation awareness was measured using the SAGAT, which provides an objective measure of SA based on queries during freezes of a simulation (Endsley, 1988). During the simulated experimental task, the mission was paused and the participant was given a questionnaire (see Annex F) on the location (both Map view and Sensory view) of the MAV at that particular pause point. The participant's answer was compared with the ground truth that was simultaneously collected in the computer database. The comparison of the ground truth and perceived SA was used as a dependent variable in this study to provide an objective measure of situation awareness. The SAGAT questionnaire was administered after the first trial of the first simultaneous display mode and first sequential display mode for a total of two questionnaires on each participant.

### 3.3.4 Mental Workload

Mental workload for each experiment condition was gathered by administering a NASA TLX mental workload questionnaire (Annex E) developed by Hart and Staveland (1988). TLX focuses on six factors contributing to the workload as a pair-wise comparison: Mental Demand (MD), Physical Demand (PD), Temporal Demand (TD), Effort (EF), Performance (PF), and Frustration (FR). Since the primary interest of this study were the effort and ease of use of different display modes and command input methods when controlling a MAV, the workload measure focused on effort and temporal demand rather than performance which was evaluated by other objective measures. The "importance" list of six factors is illustrated in Table 2 below. With the list, the number marked as importance was counted and used as a weight for each factor. The weight chart is shown in the right column of Table 3 in which effort was given the highest weight (5) and performance was given the lowest weight (0). A rating scale (from 0 to 10) on each factor was provided to each participant. The mental workload for a subject was recorded as the sum of the weighted scale, which was between 0 and 15. The questionnaire was administered after the second repetition of each trial condition for a total of 5 questionnaires for each participant.

### 3.3.5 Display Switch Frequency

During the experiment, the participants were able to click an on screen button to switch display modes, either from map view to sensor view, or vice versa. The number of such button clicks was recorded into a database as display switch frequency. This frequency was used to determine how often a participant was switching views to compare the effectiveness of simultaneous and sequential display modes.

### 3.3.6 Training Time

The training session at the beginning of the experiment was intended to reduce a participant's performance variation caused by different levels of experience with touch screen and/or tactile button devices. Each participant was required to reach a pre-defined level of experience in each experimental condition before successful completion of the training session. They needed to fly the MAV using Viliv S5 from the start point (waypoint 0 in Figure 13) to the exit of the simulated building (waypoint E in Figure 13) without any incidents such as wall collisions or flying off the map. The time that a participant used during each condition in training on Viliv S5 was recorded as a dependent variable of training time. This was used to evaluate the workload based on training.

*Table 2: Importance list of TLX contributing demand factors*

| Comparisons | Importance |
|---|---|
| MD vs. PD | MD |
| MD vs. TD | TD |
| MD vs. EF | EF |
| MD vs. PF | MD |
| MD vs. FR | MD |
| PD vs. TD | TD |
| PD vs. EF | EF |
| PD vs. PF | PD |
| PD vs. FR | FR |
| TD vs. EF | EF |
| TD vs. PR | TD |
| TD. vs. FR | TD |
| EF vs. PF | EF |
| EF vs. FR | EF |
| EF vs. FR | FR |

*Table 3: NASA TLX item weight chart*

| | |
|---|---|
| Mental Demand | 3 |
| Physical Demand | 1 |
| Temporal Demand | 4 |
| Effort | 5 |
| Performance | 0 |
| Frustration | 2 |
| Total Weight | 15 |

## 3.4 The Tasks

### 3.4.1 The Baseline Walking Task

The walking task was conducted in the training session on a PC with a 17” LCD monitor (display characteristics are described in section 2.1) for participants to get familiar with the experimental environment. It involved the following steps:

1. From starting location 0 as indicated in Figure 13,
2. Navigate the playable character to the North West towards waypoint 1 on the road,
3. Follow given waypoints 2 and 3 as shown in Figure 13,
    a. Go south on the road until a bus is seen,
    b. Locate the building to the East of the bus with an open door, and
    c. Enter the building through this door.
4. Locate and carefully make your way up the staircase inside the building, and
5. Locate the Non-Playable Target Character (NPTC; represented by red dot in Figure 13) and step on the crate to the right of the NPTC seen in Figure 14.

*Figure 14: Non-Playable Target Character (centre) and crate (right)*

### 3.4.2 The MAV Fly Task

This task was conducted on both PC and Viliv S5 for both training and experimental sessions. It has the following six steps:

1. From starting location 0 as indicated in Figure 13 (Auto mode),

2. Fly through the predefined way-markers 1, 2 and 3 in the map view (Auto mode),

3. Turn heading dial towards East to face the predefined building, and lower the altitude to 6.2 m AGL (At Ground Level) (Manual mode),

4. Locate building to the East of the bus and fly through window A as shown in Figure 13 (Manual mode),

5. Identify the NPTC in the room (Manual mode), and

6. Fly out of the room through window E as shown in Figure 13 (Manual mode).

The MAV fly task was completed with both Auto mode and Manual mode. The experiment data were collected and analyzed in terms of tasks completed in both Auto mode and Manual mode.

## 3.5 Counterbalancing with Trial Order

Since a 2 x 2 factorial design was used in this experiment, experimental conditions were counterbalanced across participants to prevent learning effects from contaminating the data. That is half of the participants received the simultaneous display mode condition first and sequential display condition second. This order was reversed for the other half of the participants. Control input condition was also counterbalanced across all participants. That is, half of the participants received the touch screen condition first and the tactile button condition second. This order was reversed for the other half of the participants. Thus, participants were required to be randomly divided to form four groups for a completed balanced design, as shown in Table 4. Each group had 11 participants who had the same experimental trial orders.

*Table 4: Experimental trial order for each group*

| Group Number | Trial 1 (Handheld) | Trial 2 (Handheld) | Trial 3 (Handheld) | Trial 4 (Handheld) | |
|---|---|---|---|---|---|
| 1 | To-Si | Ta-Si | To-Se | Ta-Se | |
| 2 | Ta-Si | To-Se | Ta-Se | To-Si | + Questionnaires |
| 3 | To-Se | Ta-Se | To-Si | Ta-Si | |
| 4 | Ta-Se | To-Si | Ta-Si | To-Se | |

## 3.6 The Procedure

The experiment consisted of two separate sessions for each participant, and all were conducted in succession within a day. The first session was for training which lasted about 60 minutes. The following experiment session had four trials which lasted approximately 15 minutes each with short breaks in-between. It was then followed by a 15 to 20 minute question and debriefing period. The total allotted time was about 3 hours, including the breaks.

The training session was conducted on two PCs and one Viliv S5 handheld device. This session had seven parts and the part orders were specified as follows:

Part 1: Environment familiarization and training for the baseline walking task PC 1;

Part 2: GUI familiarization training for the MAV fly task on PC 2;

Part 3: Short 5-minute break;

Part 4: Training for Trial 1 - MAV fly task on Viliv S5 (see Table 4 for group order);

Part 5: Training for Trial 2 - MAV fly task on Viliv S5 (see Table 4 for group order);

Part 6: Training for Trial 3 - MAV fly task on Viliv S5 (see Table 4 for group order);

Part 7: Training for Trial 4 - MAV fly task on Viliv S5 (see Table 4 for group order).

In Part 1, participants controlled the playable character on PC 1 in the 3D virtual environment using a keyboard and mouse in order to get familiar with the mission. The mouse was used to control the gaze direction of the player. The A, W, S, and D keys on the keyboard were used to control the movement of the player. In Part 2, participants used PC 2 to get familiar with two GUI display conditions (simultaneous display and sequential display), the functionality of the system, and the experimental MAV fly task (see section 3.4.2). PC 2 was used to replicate the connection to server method from each GUI to control the MAV. From Part 4 through 7, the handheld device training was executed on the Viliv S5 in a specified order based on a participant's group number for experimental trials (as shown in Table 4). Each of these four parts was timed individually from the moment the training began until the moment the fly task was successfully completed without any incidents such as wall collisions or flying off the map. This process familiarized participants with the operational environment, the different control types and display modes, as well as the task. The training times were recorded from the PC baseline walking task for the playable character and handheld training with each condition and used for learning effect analysis purposes and to examine for correlation between PC and handheld task training.

After completing the training session, participants conducted the experimental session including four MAV fly task trials on Viliv S5. The order of trials was based on individual participants' group number as shown in Table 4. Participants repeated each trial twice in each condition.

## 3.7 Data Collection and Verification

The experiment data including the playable character data, MAV data, all the events from client and server during training and experiment sessions were recorded automatically and manually. The data logging module within the server logged all the data to a text file. Then this text file was organized and exported into a single Microsoft Office Excel sheet for further analyses.

Six dependent variables were recorded during the experiment. Four of the six were automatically recorded by the computer throughout the experiment. They were (1) trajectory error, (2) task completion time, (3) display switch frequency, and (4) training time. The two other variables that were manually recorded and calculated based on questionnaires were (1) NASA TLX and (2) SAGAT.

To facilitate the registration of a data set to the corresponding trial, the recorded playable character or MAV trajectory was plotted on the map. These plotted trajectories allowed the experimenter to visually verify whether the recorded data had any sporadic errors when the data were logged or when it were imported into the Excel sheet for analysis.

Figure 15 below shows the visualized trajectory of the playable character from an experimental trial. The yellow cross indicates the defined waypoints. The yellow circles show the name of each waypoint. The dotted blue line shows the trajectory of the playable character.


*Figure 15: A visual trajectory from the playable character data record*

Figure 16 shows the flight path from an experimental trial. The dotted yellow line shows the MAV route travelled. The blue crosses show the waypoints and the blue circles show the name of the waypoints. The white MAVs show the closest position and heading relative to the defined waypoints. The blue MAV over the green shows the position and heading when the system was paused for the SAGAT questionnaire.

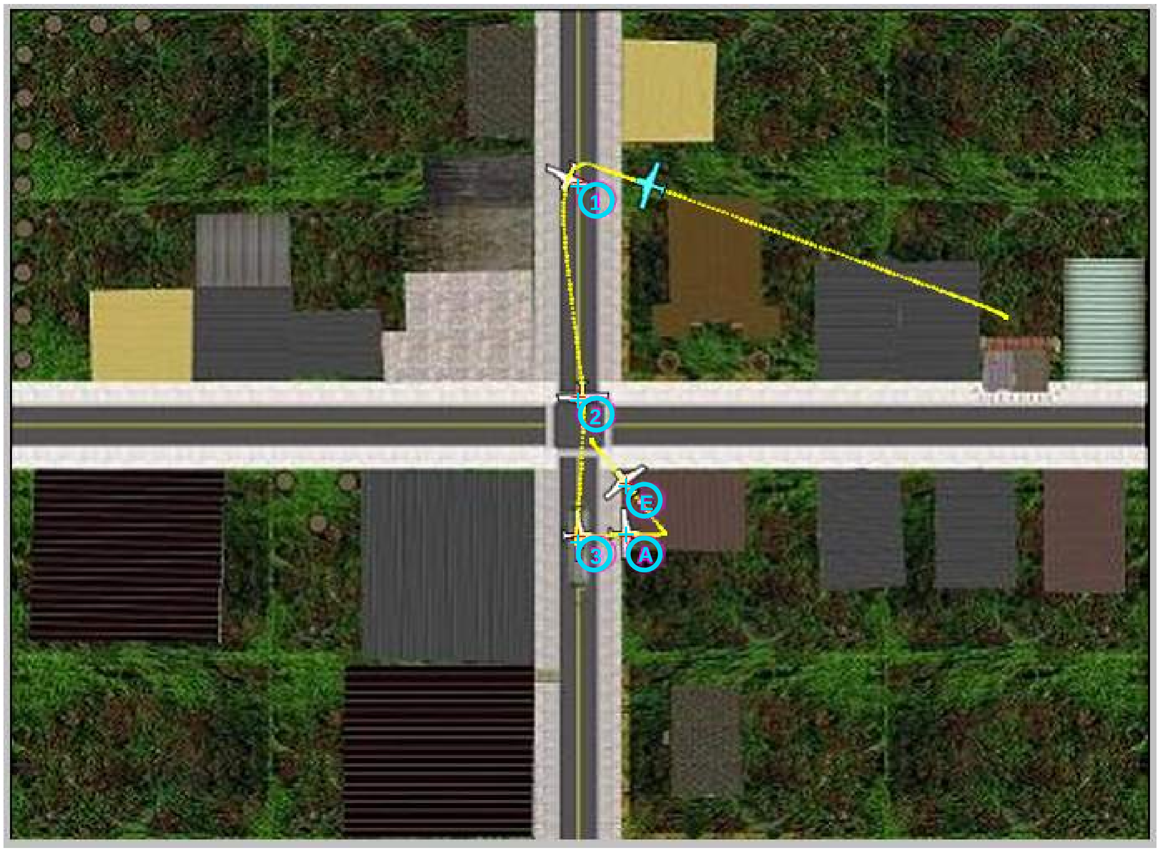


*Figure 16: A visual trajectory from the MAV data record*

# 4 Experimental Results

## 4.1 Analytical Method

After the data were retrieved, the Analysis of Variance (ANOVA) was performed on each dependent variable with respect to two factors: display mode and control input type. To examine the correlation between PC and handheld devices for training and their effects on all six measures, a multivariate analysis of covariance (MANCOVA) was also used for covariate analysis. The software STATISTICA™ version 9 was used to conduct the analyses. The results and associated 95% confidence intervals for both display mode and control type factors are presented in the following sections for six dependent variables.

## 4.2 Trajectory Error

The mean trajectory error as a function of control type is shown in Figure 17. Control type had a significant effect on trajectory error, $F(1, 173) = 4.35$, $p < .05$. The touch screen input method yielded larger trajectory errors (55.99 cm) than the tactile button input (50.49 cm). There were no other significant effects, $p > .05$ and there was no interaction between display mode and control type, $p = 0.28$.

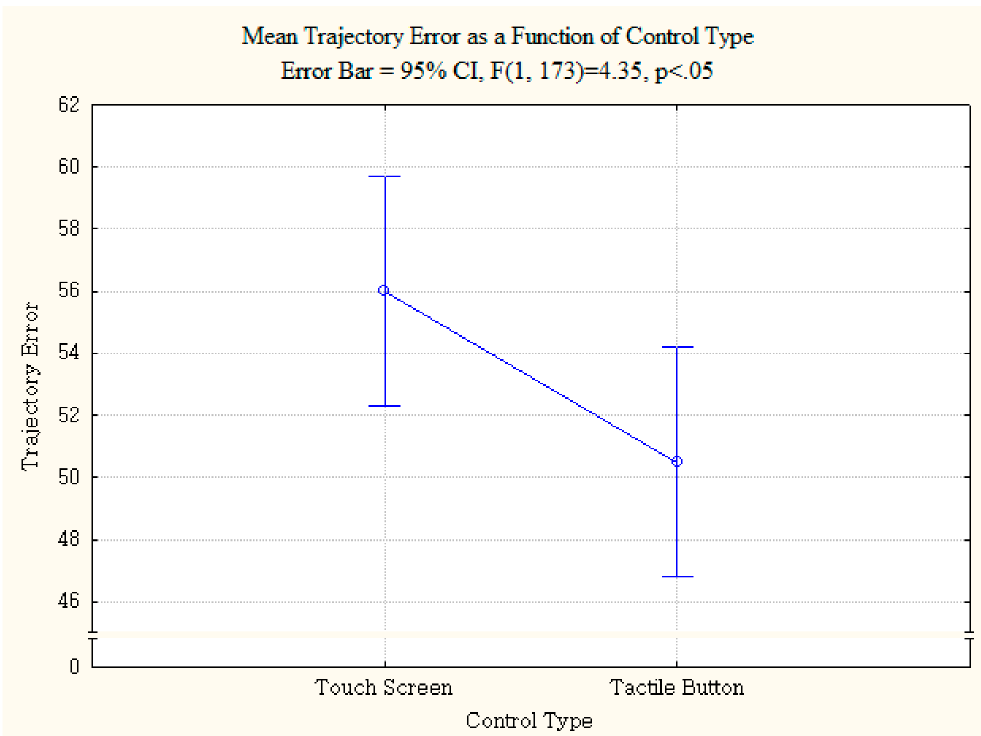


*Figure 17: Trajectory error plot*

## 4.3 Task Completion Time

The task completion time as a function of control type is shown in Figure 18. Control type had a significant effect on the time to complete the task, $F(1, 173) = 32.24$, $p < .05$. The touch screen yielded a shorter task completion time (139 s) than tactile buttons (166 s). There were no other significant effects, $p > .05$.

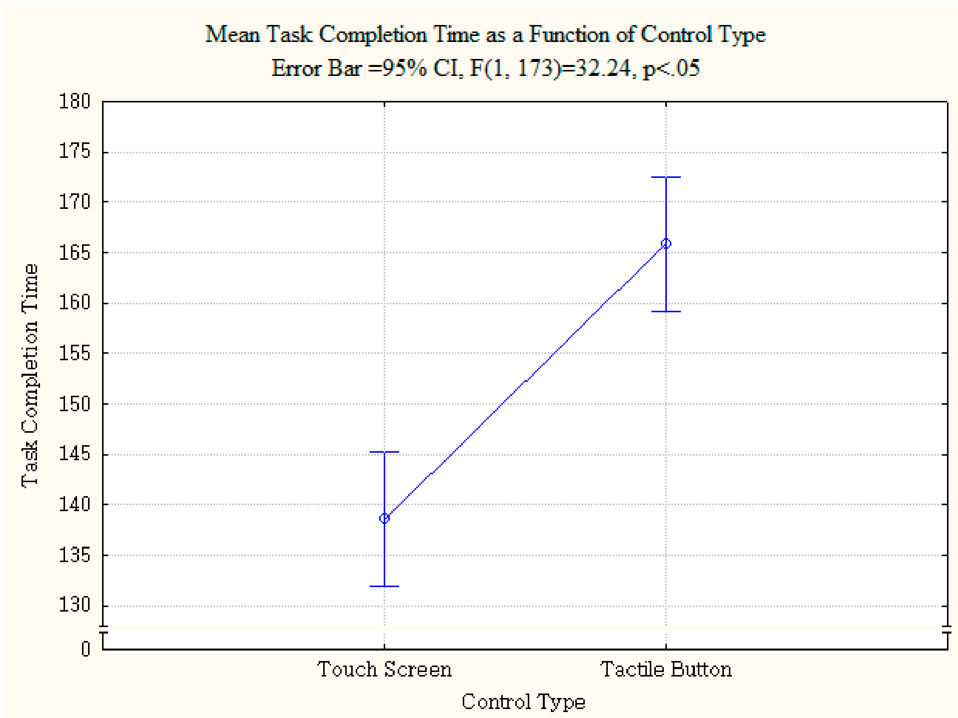


*Figure 18: Task completion time plot*

## 4.4 Situation Awareness

SAGAT data as a function of display mode and control type are shown Figure 19 and Figure 20. Both display mode and control type had significant effects on SAGAT, with $F(1, 85) = 9.72$, $p < .05$ for display mode and $F(1, 85) = 9.77$, $p < .05$ for control type. Simultaneous display led to higher SA ratings than sequential display. The touch screen control type also led to higher SA ratings than tactile buttons.

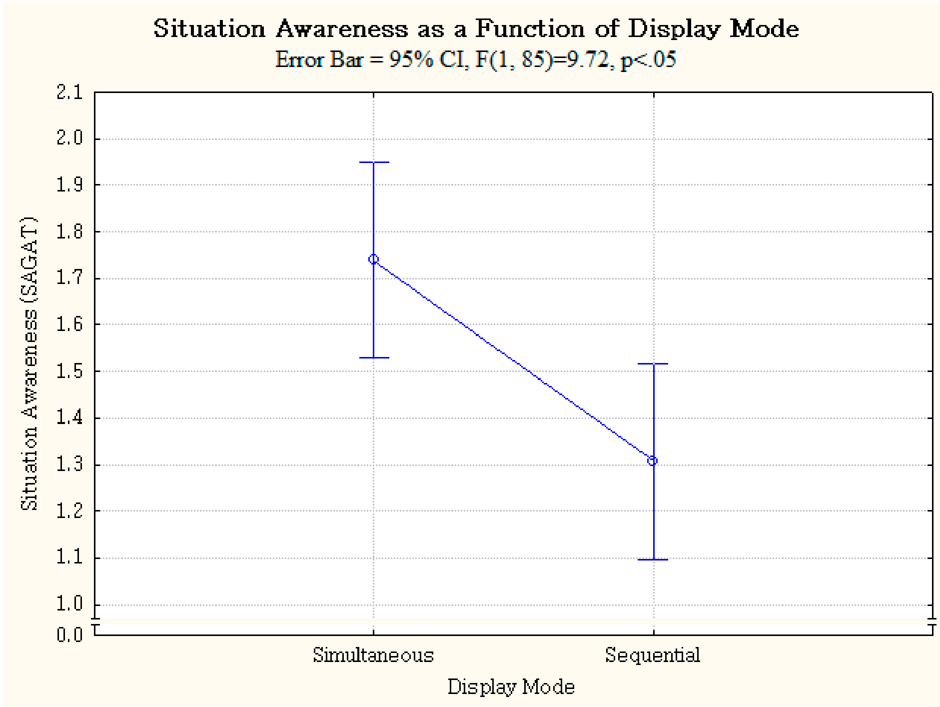


*Figure 19: Situation awareness SAGAT plot for display mode*

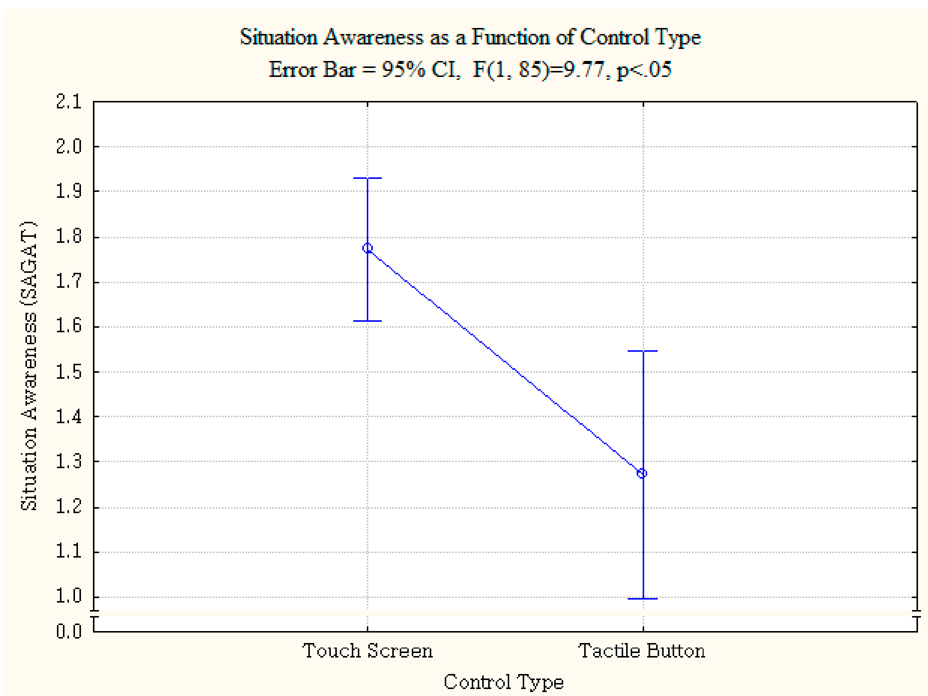


*Figure 20: Situation awareness SAGAT plot for control type*

## 4.5 Mental Workload

Mental workload as a function of display mode and control type is shown in Figure 21. Control type had a significant effect on mental workload, $F(1, 173) = 14.16$, $p < .05$. The perceived mental workload was lower for the touch screen condition than the tactile button condition.

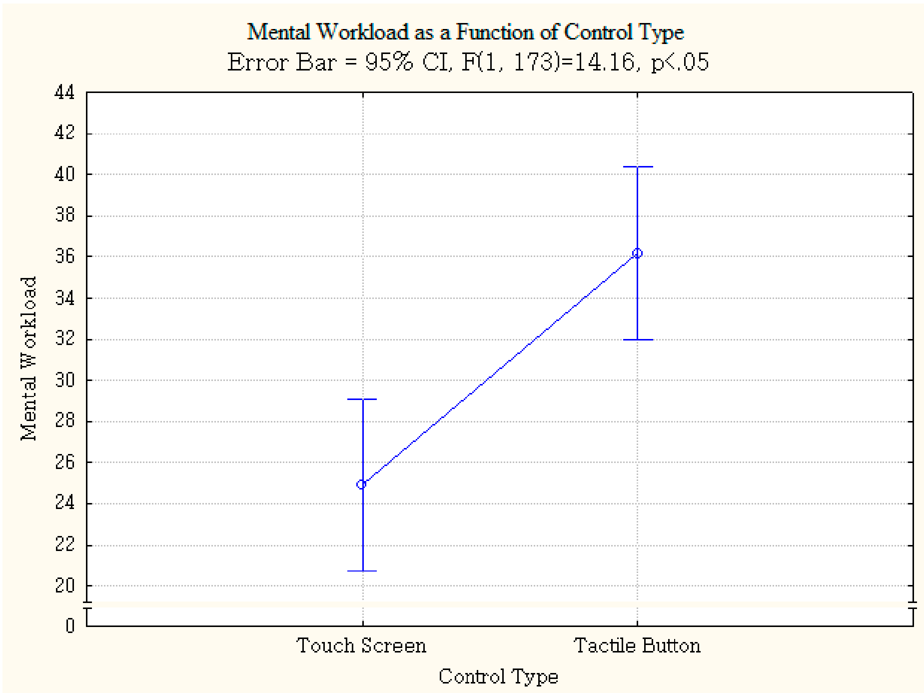


*Figure 21: Mental workload plot*

## 4.6 Display Switch Frequency

Display switch frequency as a function of display mode and control type is shown in Figure 22. Display mode had a significant effect on display switch frequency, $F(1, 173) = 23.69$, $p < .05$. Simultaneous display mode yielded a significantly lower display switch frequency (2.9 switches) than sequential display mode (4.8 switches). Control type also had a significant effect on display switch frequency, $F(1, 173) = 5.00$, $p < .05$. The touch screen control type yielded more display switch (4.3 switches) than the tactile button control type (3.39 switches). There was an interaction between display mode and control type, $F(1, 172) = 5.40$, $p < .05$. Control input type made a difference only for the sequential display condition, where the touch screen (5.75 switches) generated more switch frequency than tactile buttons (3.96 switches).

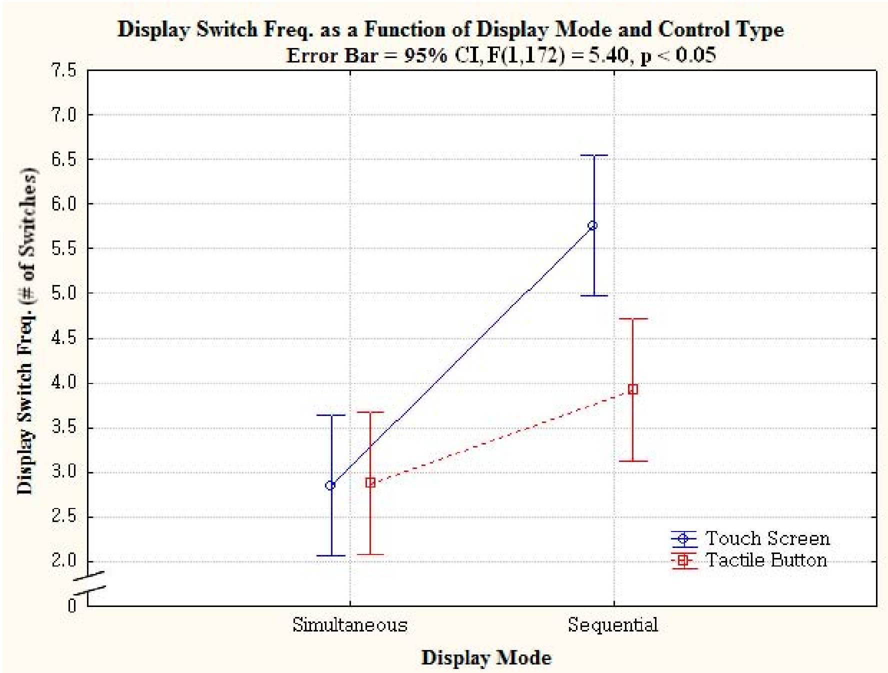


*Figure 22: Display Switch Frequency Plot*

## 4.7 Training Time

Training time on handheld device as a function of display mode and control type is shown in Figure 23. Control type had a significant effect on training time, $F(1,173) = 3.96$, $p < .05$. The touch screen control type yielded a shorter training time (202.58 s) than tactile buttons (229.78 s).

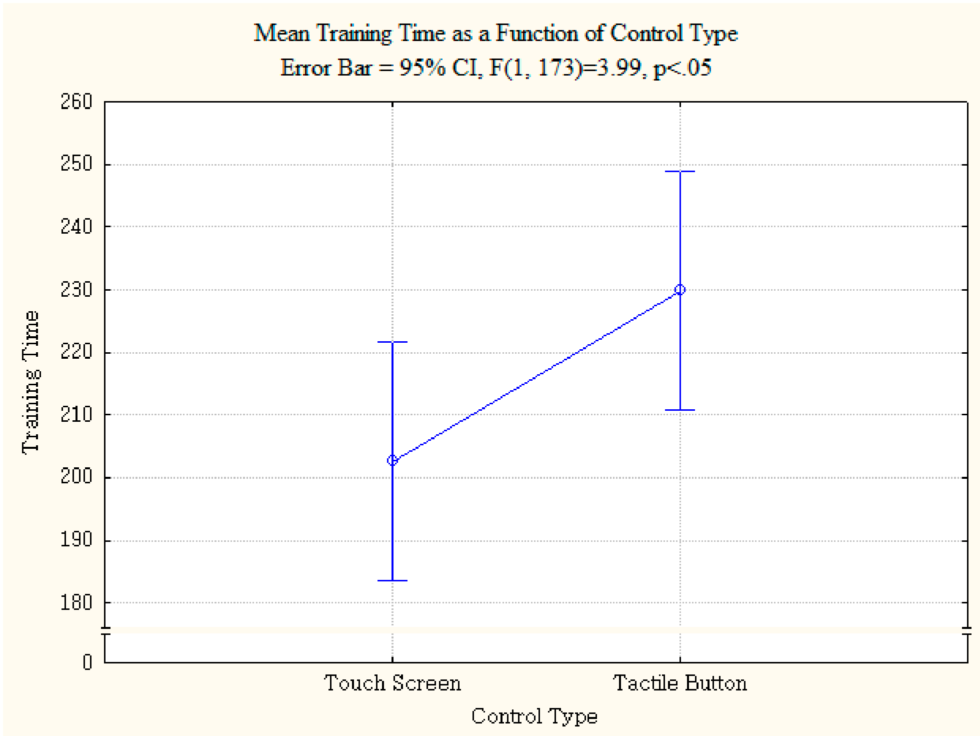


*Figure 23: Training Time Plot*

## 4.8 PC Baseline Walking Training and Handheld Task

The training times were recorded from the PC baseline walking task for the playable character and the handheld fly task with each condition. The ANCOVA analyses were conducted using display mode and control type as independent variables, training time on PC baseline walking task as a covariate, and each of the six measures as dependent variables. The analyses produced the similar result as the ANOVA analyses without PC baseline training. The MANCOVA analysis was also conducted using display mode and control type as independent variables, training time on PC baseline walking task as a covariate, and all six measures (trajectory error, task completion time, situation awareness, mental workload, display switch frequency and training time) as dependent variables. The analysis showed no significant effect.

# 5 Observations and Discussions

The results of the experiment provided empirical evidence for the development of an effective GCS and could contribute to a SOR for the control of MAV systems. The observations and discussions are presented here.

## 5.1 Display Mode

The basic task of this study for participants is to remotely navigate a MAV through waypoints to fly into a window of a building and fly out. Participants needed to plan waypoints and find optimal entry and exit positions of the building to avoid collisions. This nature of the MAV control needs to have both global (map) and local (sensor) views provided by a GUI though these two views may not be needed simultaneously all the time. With the sequential display, there was only one map or sensor view in the display. Participants had to click the sensor or map view icon on the upper right corner of the screen to get the map or sensor view. They had to switch back and forth between map view and sensor view to be fully aware of both global and local situations to accomplish the tasks. With the simultaneous display, both sensor and map views were on one display. Both global and local information was provided although one view at the top was smaller than the other. It allowed participants to be aware of the situation without time delay or visual feedback (display) lag. This is likely the reason why the simultaneous display mode provided significantly better SA than the sequential display mode, as measured with the SAGAT.

Again, both map and sensor views were needed for planning waypoints and entry and exit positions through building widows for the MAV. Having both map and sensor views on one display, the simultaneous display provided both global and local information. Participants did not need to switch back and forth between the map and sensor view unless they required a large specific view. For example, they might have to switch from a map view to a sensor view to get detailed local information when they were planning to fly into and fly out the building window. They might not need to always switch from a sensor view to a map view which could still provide global information without details due to the small window. However, the sequential display which had only one view at a time. Participants had to switch back and forth between map view and sensor view to have both global and local information. This perhaps is the reason why the simultaneous display mode provided a lower display switch frequency than the sequential display mode.

After having repeated the mission many times during the training session, the participant was familiar with the task, and may not have found difficulties in the task itself between the simultaneous and sequential displays. This probably is why the perceived mental workload, which was recorded after the second repetition of each trial condition, was very similar between simultaneous and sequential display modes. This may be the reason why trajectory error, task completion time, and training time were also similar between simultaneous and sequential displays.

The de-briefing questionnaire showed that all participants preferred the simultaneous display mode over the sequential display mode.

## 5.2 Control Type

The experiment results revealed that the touch screen control type was the overall preferred command input method. Based on the observations in the experiment, participants found it frustrating to use the tactile buttons because it was difficult and time consuming to navigate the cursor to the next command. If participants were not cautious when moving the cursor, it would overshoot the command, which impeded the accuracy and speed of the mission. This is likely the reason why participants needed less training time when using touch screen than using tactile buttons. Perhaps for the same reason, participants produced lower mental workload scores when using the touch screen than when using tactile buttons. Under less mental workload, participants had better SA when using touch screen than using tactile buttons.

With the touch screen, it needed only one click on a function icon on the display when selecting the function using a stylus (e. g., switch back and forth between map and sensor views). However, with tactile buttons, participants had to control a tactile mouse on the handheld device and move the cursor to the desired function icon on the display and then press a button to select the function. This is likely the reason why task completion time was shorter using the touch screen control than using tactile buttons. Sometimes participants were frustrated with the difficulty to control small tactile buttons on the device and gave up the control. The de-briefing questionnaire showed that all participants preferred the touch screen over tactile buttons. It might be the reason why the touch screen generated more display switches than tactile buttons.

The wide tip of the pointing device used as the touch screen control type (stylus) might have made the control less accurate. It might the reason why the touch screen yielded larger trajectory errors than tactile buttons. Thus there was a speed-accuracy trade-off for the touch screen command input method.

## 5.3 Interaction Between Display Mode and Control Type

There was an interaction between display mode and control type for the measure of display switch frequency. Control input type made a difference only for the sequential display condition, where the touch screen generated a higher switch frequency than tactile buttons. To navigate the MAV through the building blocks and flying through windows needed to have both map and sensor information. In the simultaneous display mode, one display provided both global (map) and local (sensor) information. However, in the sequential display mode, there was only one view on one display. It was needed to switch back and forth between map view and sensor view to get more information. Thus the switch frequency in the sequential display mode was higher than the simultaneous display for both the touch screen and tactile buttons. With the touch screen, participants could just make one click using the stylus on the upper right corner icon to switch between map and sensor views. But using tactile buttons, participants had to control the mouse to move the cursor onto the upper right corner icon and press another button to select the view to switch. Due to the difficulty to control small tactile buttons to select functions, they might be reluctant to use them as often as using a stylus to click on the display. This might be the reason why participants generated a lower switch frequency using tactile buttons than using the touch screen. Therefore, there existed an interaction between display mode and control type.

## 5.4 PC Baseline Walking Task and Skill Compensation

The introduction of PC baseline walking task was to compensate participants' different PC skills. Another purpose was to investigate whether there was a correlation between participants' PC skills and their experiment performance on handheld devices. However, the experiment was designed in such a way that each participant was tested on all four experiment trial conditions so that his/her PC skills would be contributed to each trial condition. Perhaps this is the reason why both the ANCOVA and MANCOVA results revealed no effect of training time on PC baseline walking task on the outcomes of the experiment. In the other words, the experiment procedure might have compensated the participants' different PC skills.

## 5.5 Feedback

Most participants preferred the touch screen and simultaneous display over tactile buttons and sequential display. However, they also indicated that the touch screen input method was not as precise when plotting the waypoints. Some participants preferred using the tactile buttons when creating waypoints. On the other hand, most participants preferred to use the touch screen during manual flight since it was too time consuming to move the cursor and press to confirm the choice with tactile buttons. A couple of participants also pointed out that from the practical perspective, the touch screen would be difficult to use when wearing a pair of gloves in the field.

# 6 Conclusions

The purpose of the study was to provide guidance for the future development for GCS interface design. The experimental results revealed that the display mode and control type had significant effects on the operation of a MAV using a handheld device. The simultaneous display provided better SA and fewer display switches compared with the sequential display. The touch screen produced a quicker task completion time and larger trajectory error than tactile buttons, resulting in a speed-accuracy trade-off. The touch screen also facilitated a shorter training time than tactile buttons. Additionally, participants reported better SA and lower mental workload using the touch screen than using tactile buttons.

The research findings provided guidance for user interface design of a GCS on a handheld device. For better SA, the interface should be designed with a combination of both sensor and map views. For the ease-of-control, a handheld device with a touch screen is preferable over a device with tactile buttons. These findings provided empirical evidence for the development of SOR of MAV systems, but require validations from field studies.

# References


Billings, D. R., & Durlach, P. J. (2008). The effects of input device and latency on ability to effectively pilot a simulated micro-UAV. In *Proceedings of Human Factors and Ergonomics Society Annual Meeting, 52*(27), 2092-2096.

Endsley, M.R. (1988). Design and evaluation for situation awareness enhancement. In *Proceedings of the 32nd Annual Meeting of the Human Factors Society* (pp. 97-101). Santa Monica, California: Human Factors Society.

Faul, F., Erdfelder, E., & Buchner, A. (1996). G*Power: A general power analysis program. *Behavior Research Methods, Instruments, & Computers, 28,* 1-11.

Fong, T. W., Cabrol, N., Thorpe, C., & Baur, C. (2001). A personal user interface for collaborative human-robot exploration. In *Proceedings of the International Symposium on Artificial Intelligence, Robotics, and Automation in Space*. Montréal, Canada.

Hart, S. G. & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. A. Hancock, & N. Meshkati (Eds.), *Human Mental Workload* (pp. 139-183). Amsterdam, Holland: North-Holland.

Haylock, T. M (2008). A prototype user interface for the control of extremely agile micro-aerial vehicles. In *Proceedings of Unmanned Vehicle Systems Canada 2008 Conference*. Ottawa, Canada.

Hou, M. & Kobierski, R. D. (2006). Operational analysis and performance modelling for the control of multiple UAVs from an airborne platform. In N. J. Cook, H. Pringle, H. Pedersen, & O. Connor (Eds.), *Advances in Human Performance and Cognitive Engineering Research, Vol. 7. Human Factors of Remotely Operated Vehicles* (pp. 267-284). New York: Elsevier.

Hou, M., Kobierski, R. D., & Herdman, C. (2006). Design and development of intelligent adaptive interfaces for the control of multiple UAVs. In *NATO RTO HFM-135 Symposium on Human Factors of Uninhabited Military Vehicles as Force Multipliers:* No. 25. Biarritz, France.

Hou, M., Kobierski, R. D., & Brown, M (2007). Intelligent Adaptive Interfaces for the control of multiple UAVs. *Journal of Cognitive Engineering and Decision Making*, *1*(3), 327-362.

Hou, M., Keillor, J., Wong, F., Haylock, T. M., & Somjee K (2009). Development of prototype interfaces for the control of a micro-aerial vehicle. In *Proceedings of 17th World Congress on Ergonomics*. Beijing, China.

Huttenrauch, H., & Norman, M. (2001). PocketCERO –mobile interfaces for service robots. Paper presented at the *Proceedings of Mobile HCI 2001: Third International Workshop on Human Computer Interaction with Mobile Devices*. Lille, France.

Miller, Funk, Goldman, Wu & Pate (2003) A Playbook Approach to Variable Autonomy Control: Application for Control of Multiple, Heterogeneous Unmanned Air Vehicles. Retrieved on March 2, 2008, from the World Wide Web: http://www.sift.info/publications/PDF/MGFWP-AHS04-fin.pdf.

Miller, C., & Parasuraman, R. (2006). Designing for Flexible Interaction between Humans and Automation: Delegation Interfaces for Supervisory Control. *Human Factors, 49*, 57-75.

Murphy, A., Wu, P., & Miller, C., (2007). *Literature review of HCI concepts for multiple unmanned vehicle supervisory control*. Minneapolis, MN: Smart Information Flow Technologies.

Parasuraman, R. and Miller, C. (2006). Delegation interfaces for human supervision of multiple unmanned vehicles: Theory, experiments and practical applications. In E. Salas (Ed.), *Advances in Human Performance and Cognitive Engineering Research: Vol. 7. Human Factors of Remotely Operated Vehicles* (pp. 251-256). San Diego: Elsevier.

Perlin, M. (2008). *Development of Prototype Interfaces for Controlling an EAMAV*. DRDC Contract Report, W8485-0-XKCF/A.

Quigley, M., Goodrich, M.A., & Beard, R.W. (2004). Semi autonomous human-UAV interfaces for fixed-wing mini-UAVs. In *Proceedings of IROS 2004,* 2457- 2462.

Rutley, M. (2005). *Design, rapid prototyping and evaluation of a controller interface for a remote reconnaissance vehicle*. M.Sc. thesis, Loughborough University, Loughborough, UK.

Ste-Croix, C., & Angel, H. A. (2008). Extreme Agility – Micro Aerial Vehicle Statement of Requirements Development Focus Group.

Yin, S., & Selvadurai, J. (2010). *Experiment Design for Interface Comparison on the Performance of Virtual EA-MAV Operation on Control type and Display Mode*. DRDC Contract Report, CR 2008-135.

# Annex A Experimental Protocol

February 3, 2011

**Protocol**: #L-680

**Title:** Comparison between Touch Screen and Tactile Interfaces on Performance of Virtual Unmanned Aerial Vehicle Operation

**Principal Investigator:** Dr. Ming Hou (DRDC Toronto)

**Research Assistants:** Sheila Young and Andrew Sun

**Thrust Code:** 12PN03

## A.1 Executive Summary

Extremely Agile Micro Aerial Vehicles (EA-MAVs) are miniature flying machines that will provide “over-the-hill” or “around-the-next-house” reconnaissance to smaller combat elements such as infantry sections. With the advancement of this technology, it is essential for the development of a suitable Ground Control System (GCS) to control it. Consequently, there is a requirement for human factors research to be done on the subject to help develop and deliver the most efficient user interface. One significant factor to consider is the differences between the two modern types of handheld input devices – touch screen and tactile button equipped devices. A second significant factor to consider is the difference between a graphical user interface (GUI) that combines map and video sensor data into a single window or one that divides them into separate windows. This study seeks to identify the differences in performance and efficiency of the operator when operating an EA-MAV with each of these two types of interfaces. The results will aid in the design of the final EA-MAV GCS interface device.

The experiment will be conducted with the use of the Virtual Navigation and Collaboration Experimentation Platform (VNCEP) developed by Esterline CMC, a virtual environment with a virtual EA-MAV and a GUI developed by VisImage Systems Inc., and a single handheld device; the Viliv S5 Ultra Mobile Personal Computer (UMPC). The participants will take the role of a soldier operating an EA-MAV through a simulated interface. They will fly through a virtual urban terrain and into a building with full control over the EA-MAV using the Viliv S5.

The experiment conforms to Defence Research and Development Canada (DRDC) - Toronto guidelines with respect to selection, payment, and treatment of human participants. Possible risks to the subject are minimal and may include mild fatigue or eyestrain from performing the task and/or using the computer or a handheld device. The nature of the experiment, including potential risks, will be explained in detail to volunteer participants who will read and sign a form to indicate informed consent. The differences in efficiency and performance when using touch screen vs. traditional tactile controllers and when using different GUI views have not been examined extensively in this application, and the findings will provide a starting point in understanding how EA-MAV GCS can be optimized. More specifically, they will provide valuable information towards the final design and construction of the GCS interface for the EA-MAV project.

DRDC Experiment Protocol

**Title:** Comparison between Touch Screen and Tactile Interfaces on Performance of Virtual Unmanned Aerial Vehicle Operation
**Protocol:** #L-680
**Principal Investigator:** Dr. Ming Hou (DRDC Toronto)
**Research Assistants:** Sheila Young and Andrew Sun
**Thrust Code:** 12PN03

## A.2 Glossary of Acronyms

| | |
|---|---|
| DRDC Toronto | Defence Research & Development Canada - Toronto |
| DRDC Valcartier | Defence R&D Canada – Valcartier |
| GCS | Ground Control Station |
| GUI | Graphical User Interface |
| EA-MAV | Extremely Agile Micro Aerial Vehicle |
| LCD | Liquid Crystal Display |
| MANCOVA | Multivariable Analysis of Covariance |
| MAV | Micro Aerial Vehicle |
| NASA TLX | NASA Task Load Index |
| NPTC | Non-playable Target Character |
| PC | Personal Computer |
| PDA | Portable Digital Assistant |
| SAGAT | Situation Awareness Global Assessment Technique |
| UMPC | Ultra Mobile Personal Computer |
| UV | Unmanned Vehicle |
| VGA | Video Graphics Array |
| VNCEP | Virtual Navigation and Collaboration Experimentation Platform |

## A.3 Ethics Committee Proposal

### A.3.1 Background

Micro Aerial Vehicles (MAVs) are miniature flying machines that will provide “over-the-hill” or “around-the-next-house” reconnaissance to smaller combat elements such as infantry sections. The device that will become the Extremely Agile Micro Aerial Vehicle (EA-MAV) is an electric fixed wing aircraft equipped with a Video Graphics Array (VGA) video sensor and an audio sensor. The hardware prototype is currently under development at Defence Research & Development - Valcartier (DRDC Valcartier). Its forward flight speed can vary from a standstill to a running pace. In hovering mode with the nose pointed vertically up, the MAV can roll about its longitudinal axis to scan the surroundings with the video sensor. Using onboard electronics, the MAV will automatically stabilize its altitude. While the MAV is recoverable, depending on the tactical situation, the soldier may discard the MAV due to its low cost.

To utilize such technology, soldiers will require a Ground Control Station (GCS) to interact with whatever flying device they are operating. The GCS itself is subject to stringent engineering criteria, such as the need to be robust enough to withstand extreme heat, moisture and acceleration. The interface must be easy to learn for the average soldier, and be intuitive in function so that time is not lost during mission-critical moments in deciphering what the next control sequence should be. This device must be small and light enough to not seriously hinder the soldier who will be carrying it. To date, little human factors work has been done on what is the most desired method for controlling such a device.

A number of hand held devices have been developed for use with modern Unmanned Vehicles (UVs) and robots. These include Personal Digital Assistants (PDAs), portable laptops, touch screen tablets, and modular systems. Handhelds may either serve as a component of a larger ground control station as the operator interface or video interface, or they can function as the integrated ground control station. The latest trend in ground UV operation has seen the use of game-style hand controllers with laptops and tablets. Experiments have shown that game-style controllers (Xbox 360) have led to faster training and easier operation in the field [1]. Within this class of control system device, the type of input technology is an important consideration. The two modern input methods are capacitive or resistive touch-sensitive display, and tactile hardware buttons, which provide haptic feedback.

To control the EA-MAV through a GCS, the soldier requires a Graphical User Interface (GUI) to be embedded that will allow them to interact with whatever flying device they are operating. The GUI itself is subject to stringent human factors engineering criteria, such as the amount of sensory data displayed, screen size, resolution, and optimized map and video sensor views. Additionally, the GUI must be easy to learn for the average soldier, and be intuitive in function and display so that time is not lost during mission critical moments. There has been research into over-layer and split views of sensory and map data but not into picture in picture views.

This investigation attempts to examine the differences in operator performance between two interface conditions. The first condition compares touch-screen and tactile input methods, while the second condition looks at two GUI layouts: separated sensor view and map view, versus combined sensor view and map view. The findings will not only assist in choosing the optimal input and display method for the final GCS interface system, but will also set a base for future experimentation and research on interfaces using this platform.

### A.3.2 Purpose of Study

This study aims to determine how the performance of an EA-MAV operator is affected by two experimental conditions: (i) Input Control Type - Touch Screen versus Tactile Button, and (ii) Display Mode (sensor view and map view) - Sequential view versus Simultaneous view.

### A.3.3 Selection of Human Participants

Approximately 36 civilian and military volunteers from Defence Research & Development - Toronto (DRDC Toronto) and the surrounding community, aged 18-60 with self-reported normal or corrected-to-normal vision, including normal colour vision, will be recruited by email. Both males and females will be eligible to participate. Participants will be financially compensated for stress allowance according to DRDC guidelines. Investigators will not serve as participants in this experiment.

### A.3.4 Methodology

*Stimuli and Apparatus*

The experiment will be conducted in DRDC Toronto, Room 2000 with normal temperature. The visual stimuli will be delivered using different hardware based on the trial session. There will be six separate sessions, all conducted on one day in succession. Each of the sessions will utilize one of the different input methods for EA-MAV control; a Viliv S5 Ultra Mobile Personal Computer (UMPC) (see Figure A-1) (a product by Yukyung Technologies Corporation located in Anyang-si, Gyeonggi-do South Korea), and a standard Personal Computer (PC) with a keyboard and mouse that will be used as a baseline. The order of these sessions will be counterbalanced across participants to account for learning affects.

The first session will be conducted on a Windows-based workstation with a Liquid Crystal Display (LCD) with screen dimensions 41 cm x 31 cm and a resolution 1280 x 1024 pixels running the latest version of the Virtual Navigation and Collaboration Experimentation Platform (VNCEP) virtual environment software. The participant will be seated approximately 55 cm away from the monitor. In this session, the participant will control the playable character in the 3-Dimensional virtual environment using the keyboard and mouse. The mouse will control the gaze of the player and the A, W, S and D keys will control the movement of the player. The participant will use the same workstation to view the two GUIs and then familiarize themselves with the functionality of the system and the experiment fly-task.

In the second session, the participant will use the same workstation as above to complete the PC baseline experiment task.


*Figure A-1: Viliv S5 UMPC*

In all the following sessions (3-6) the participant will use a Viliv S5 UMPC to control the EA-MAV in the virtual environment. The Viliv S5 UMPC, displayed above in figure A-1, is a commercially available ultra mobile personal computer with a screen size of approximately 10.5cm x 6.3cm and a screen resolution of 1024 x 600 pixels.

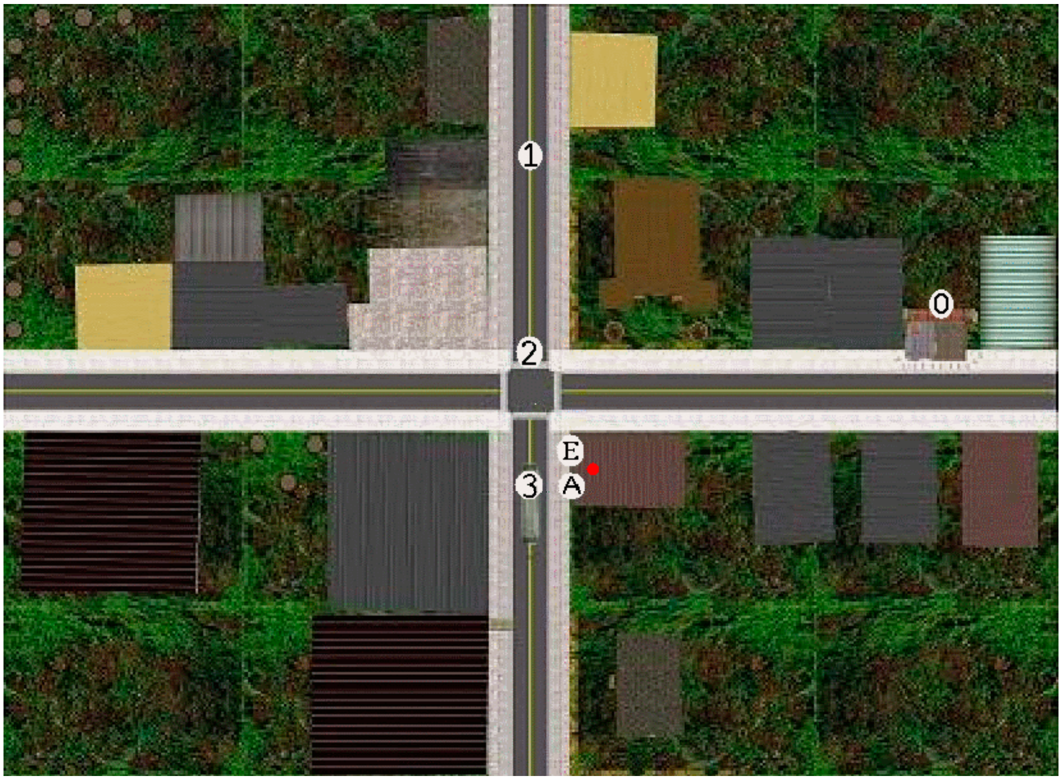


*Figure A-2 - The Task Mission*

Note, in Figure A-2, the Way-marker definitions are as follows:

0: Starting Location

1, 2, 3: Aligned with center of road to be traveled in auto mode

A: Access - Entry Location. Aligned with the center of the far right second story window to fly into of the building

E: Exit - Finishing Location. Aligned with the center of the far left second story window to fly out of the building

Red Dot: Location of the Non-playable Target Character (NPTC)

In the third session, the screen will display a sensor image stream from the virtual EA-MAV's VGA sensor and on a separate tab. Once selected, the screen displays a bird's-eye view of the map with an indicator showing the relative location of the EA-MAV. During this session the participant will complete the task mission by flying through the way-markers as shown in figure

A-2, and will control the EA-MAV using only the hardware buttons and the sequential view GUI. Once complete, the user will be given the task questionnaire and the situational awareness questionnaire.

In the fourth session, the screen will display a sensor image stream from the virtual EA-MAV's VGA sensor and on a separate tab. Once selected, the screen will display a bird's-eye view of the map with an indicator showing the relative location of the EA-MAV. The screen will display the same GUI used in the second session. During this session the participant will complete the task mission by flying through the way-markers as shown in figure A-2, and will control the EA-MAV using only the touch-sensitive screen and none of the tactile buttons and the sequential view GUI. Once complete, the user will be given the task questionnaire.

In the fifth session, the screen will display a large sensor image stream from the virtual EA-MAV's VGA sensor with a small view of the bird's-eye view map and the relative location of the EA-MAV and on a separate tab. Once selected, the screen displays a large bird's-eye view of the map with an indicator showing the relative location of the EA-MAV, and a small view of the virtual EA-MAV's VGA sensor. During this session the participant will complete the task mission by flying through the way-markers as shown in figure A-2, and will control the EA-MAV using only the hardware buttons and the simultaneous view GUI. Once complete, the user will be given the task questionnaire (Annex E) and the situational awareness questionnaire (Annex F).

In the sixth session, the screen will display a large sensor image stream from the virtual EA-MAV's VGA sensor with a small view of the bird's-eye view map and the relative location of the EA-MAV and on a separate tab. Once selected, the screen displays a large bird's-eye view of the map with an indicator showing the relative location of the EA-MAV, and a small view of the virtual EA-MAV's VGA sensor. The screen will display the same GUI used in the fifth session. During this session, the participant will complete the task mission by flying through the way-markers as shown in figure A-2, and will control the EA-MAV using only the touch-sensitive screen and none of the tactile buttons and the sequential view GUI. Once complete, the user will be given the task questionnaire (Annex E).

The participant will be asked to navigate the EA-MAV as quickly as possible from the launch site following the defined path to a specified building in the scenario, which has been identified as a possible threat. Once there, the participant will have to navigate the EA-MAV accordingly to enter the building through a second story window. The participant will operate the EA-MAV to view the NPTC (illustrated in figure A-3 below) and then exit through the window on the far left.

During the second baseline session, the participant will follow the same scenario except on foot as a playable character. At the building containing the possible threat, they will enter through a doorway on the ground level directly below the second story window and use stairs to reach the NPTC.

*Figure A-3: Example of the Sensor Image as seen by the EA-MAV*

### A.3.4.1 Experimental Procedure

The experiment will look at the two types of control interfaces; touch screen and tactile as the primary independent measure, and two types of GUIs; bird's-eye map and video sensor viewed at the same time on a single window, or a bird's-eye map and video sensor viewed individually in separate windows. The dependent measures will include response times and precision to the way-markers.

There will be six sessions completed within one day. The first session (training) will last about 60 minutes. The following five sessions will last about 15 minutes each with 5 minute breaks in-between, followed by a 20 minute question and debriefing period. The total time is set to be 3 hours with breaks included. The order of the sessions will be counter-balanced to account for learning affects.

### A.3.4.2 Data Analysis

The dependent variables for this study include mission completion time, the EA-MAV navigation path precision, Situation Awareness Global Assessment Technique (SAGAT) [2] on situation awareness, and training time. They are described in section 3.2 of reference [3]. The mission timings will be compared across the two control interfaces and the 2 display views to determine maximum performance and efficiency. The playable character's and the EA-MAV's travel path, which is along the defined way-markers, will be used to calculate the standard deviation and compared across the two interfaces, the two graphical interfaces and the baseline. The performance will be measured by the horizontal distance the EA-MAV travels from each defined way-marker and the number of times the participant fails a mission. The mission fail rate will also be measured and this will be defined by the number of times the participant controlled playable character or if a MAV collides with a stationary object, and/or flies off the map. If the participant fails a mission, they may retry the mission by selecting the 'RESET' button and they will have to begin the mission from the initial starting point.

There will be a maximum of 5 resets within the limits of the allotted 15-minute task time. The number of clicks (tactile control) and taps (touch screen control) will be recorded and analyzed to view the convenience of the simultaneous view graphical user interface versus the sequential view graphical user interface. Only the best successful mission in terms of time and performance from each participant will be used when data are analyzed. The participants will complete background information questionnaire (Annex D) before they begin training and a post-task questionnaire (Annex E) per session. The participants will also be posed with a situation awareness questionnaire (Annex F) the first time they complete the sequential view task and the first time they complete the simultaneous view task. The background information will be used to analyze the participants' demographic and experience with touch screen and tactile button input and video games. The post-task questionnaire will contain usability and workload insensitivity questions using the NASA Task Load Index (NASA TLX) [4] 10 scale ratings. The data from each participant will be entered into tables 2 and 3 shown in reference [3] and used to analyze the data retrieved by each individual, by each group and all the groups as a whole subject.

The data collected will be analyzed using the method of MANCOVA (Multivariable Analysis of Covariance) [5]. STATISTICA [6] from StatSoft will be used.

The significant differences between the means will be tested. Two independent variables are control type (2 levels: touch screen vs. button) and display mode (2 levels: sequential vs. simultaneous). Dependent variables are completion time, route error, TLX and SAGAT. The completion time in PC Baseline mission will be used as a covariate. A two-by-two within-group analysis will be used for completion time, route error and TLX. Between-group analysis will be used for SAGAT.

The interaction effect between control type and display mode, the significance level, as well as the correlation of the dependent variables with the covariate (completing time in PC Baseline mission) will be provided as a result from the MANCOVA [5].

#### A.3.4.3 Medical Screening

The experiments will require no medical screening. Participants will be asked whether they have any condition that would preclude working with a computer or the mobile handheld devices, and whether they have had changes in caffeine or alcohol intake. Any participants with such a condition will not participate.

#### A.3.4.4 Physician Coverage

The presence of a physician in the experiment room will not be necessary. All sessions will be conducted during regular working hours.

#### A.3.4.5 Roles and Qualifications of Team Members

Dr. Ming Hou, Defence Scientist as the Investigator, will determine all procedures for the experiments and be the immediate point of contact for all trials. The research assistants (Sheila Young and Andrew Sun) will contact participants, schedule trials, and conduct all training and experiment sessions. They will also be responsible to ensure the proper set-up and use of the computers and equipment.

#### A.3.4.6 Withholding of Information

The experiments involve minimum withholding of information. Participants will not be informed of the specific hypotheses and stimulus configurations of experiments. They will, however, receive thorough and truthful explanations of the purpose and procedures of the experiments before beginning. Participants will receive a debriefing that explains the specific hypotheses examined after the completion of the experiment by all participants. The participant will be informed that if they do not wish their data to be used, it will be discarded.

### A.3.4.7 Risks and Benefits

*Risks*

The experiments will be performed using common computer equipment in an office-like setting, with no stressors applied to participants. A possible risk to the subject is mild fatigue or eyestrain from performing the task and/or using the computer and devices. To minimize this effect, volunteer participants will receive a break between training and test sessions, and the experimental task will be made as engaging as possible. The nature of the experiment, including potential risks, will be explained in detail to participants who will read and sign a form to indicate informed consent. The experimental data concerning each subject will be treated as confidential (‘Protected B’ In Accordance With Canadian Forces Security Requirements) and will not be revealed to anyone other than the DRDC Toronto Investigator(s) or external investigators from the sponsoring agency without the subject’s consent, except as data unidentified as to source.

*Benefits*

The purpose of this study is to examine the difference in operator performance when using touch-screen vs. tactile button input systems. Specifically, we hope to learn if using one of these input methods is more intuitive and effective for control of the MAV in the context of a handheld portable device. These differences have not yet been examined extensively in this context and therefore, this research would benefit the scientific and technological communities at large as well. The benefit of this study to the participant is to learn about new MAV technologies under development for use in reconnaissance.

### A.3.4.8 Potential Conflicts of Interest

All funding for the experiment comes from Thrust 12PN03.

### A.3.4.9 Approximate Time Involvement

The experiment will consist of six sessions conducted in one day, with a 60-minute training session and with each of the remaining 5 sessions being approximately 15 minutes in duration each. The total estimated time for the experiment is approximately 3 hours including the breaks between sessions.

### A.3.4.10 Participant Remuneration

Based on DRDC Toronto’s Experimental Compensation Calculator, internal subjects will be remunerated a total of $22.36 and external subjects will be remunerated a total of $40.20 as well as travel costs to an amount equivalent to the cost of round-trip TTC fare for completion of this study [7].

The calculation variables are as follows:

1) Total stress level: 1 units
2) Total number of hours of participation: 3 hours
3) Pay/stress unit: $22.36 for internal participants, and $40.20 as well as travel costs to an amount equivalent to the cost of round-trip TTC fare for external participants.

### A.3.4.11 References


[1] Human System Inc., *Extreme Agility – Micro Aerial Vehicle Statement of Requirements Development Focus Group*. Defence Research and Development – Toronto Contract Report, CR 2008-135, 2008.

[2] Endsley, M.R, *Design and evaluation for situation awareness enhancement*, Proceedings of the 32nd Annual Meeting of the Human Factors Society, 1988.

[3] VisImage Systems Inc., *Experiment Design for Interface Comparison on the Performance of Virtual EA-MAV Operation on Control type: Touch Screen vs. Tactile and Display mode: Simultaneous vs. Sequential displays of map and sensor views.* Internal report, 2010.

[4] Hart, S. G. and Staveland L. E., *Development of NASA-TLX (Task Load Index):Results of Empirical and Theoretical Research.* National Aeronautics and Space Administration - Ames Research Center, 1988.

[5] Keren Gideon, Lewis Charles, "*A handbook for Data Analysis in the Behavioral Sciences*", Lawrence Erlbaum Associates, 1993.

[6] Hill, T. & Lewicki, P., "*STATISTICS Methods and Applications*" StatSoft, Tulsa, OK, USA, 2007.

[7] McLellan, T. M., et al., *DRDC Toronto guidelines for compensation of subjects participating in research studies*, Defence Research and Development Canada – Toronto Technical Memorandum, TM 2008-138, 2008.

# Annex B Participant Information Sheet

**Comparison between Touch Screen and Tactile Interfaces on Performance of Virtual Unmanned Aerial Vehicle Operation**

### Background

Extremely Agile Micro Aerial Vehicles (EA-MAVs) are miniature flying machines that will provide “over-the-hill” or “around-the-next-house” reconnaissance to smaller combat elements such as infantry sections. It is essential for the development of a suitable Ground Control System (GCS) to control it. Consequently, there is a requirement for human factors research to be done on the subject to help develop and deliver the most efficient user interface. One significant factor to consider in designing a GCS for any EA-MAVs is the difference between the touch screen and tactile hardware buttons equipped on a modern type of handheld input device. The second factor to consider is having map and sensor views combined in one window view as opposed to being split into separate windows. This study seeks to identify the differences in performance and efficiency of the operator when operating an EA-MAV with each of these two types of control interfaces and graphical user interfaces. The results will aid in the design of the final EA-MAV GCS interface device.

### Task

You will be asked to control the EA-MAV using a device and navigate it through urban terrain. First, you will navigate on a defined path to a building that has been identified as a possible threat. Once there, you will have to enter the building. It is given that the character in the room will be visible on the screen. The path to travel will be provided to you on a reference map. The simulator will automatically log the path traveled with a relative efficiency to the provided reference path and the number of commands and the entire tasks timings; these are then to be analyzed.

At the beginning, the experiment administrator will run you through a training session, which will last about 60 minutes. You will operate the user interface via Personal Computer (PC), control the device, and familiarize yourself with the mission where you will fly through a short flight path through the terrain to familiarize yourself with the inputs and the targets. After the main training session, there will be 5-recorded sessions. Each session will last for approximately 15 minutes. There are a total of six sessions, all conducted in one day with short breaks in between. If you have any questions about the experiment, the experiment administrator will answer them for you. Should you feel the need to withdraw from the experiment, you may do so at any time.

**Rights as a Participant**

Your participation in this study is completely voluntary. You are free to refuse to participate and you may withdraw your consent at any time, in which case your participation as a subject will cease immediately. You may ask questions of the Investigator(s) at any time during the training session.

**Confidentiality**
The experimental data concerning you will be treated as confidential ('Protected B' in accordance with the Canadian Forces Security Requirements) and not revealed to anyone other than the Defence Research and Development Canada - Toronto Investigator(s) or external investigators from the sponsoring agency without your consent except as data unidentified as to source.

## Benefits of Study

The findings will provide a starting point in understanding how the GCS for the EA-MAV can be optimized. The differences in efficiency and performance when using touch screen vs. traditional tactile controllers have not been examined extensively in this application. Having a bird's-eye map and a camera view combined in one window, as opposed to being split into separate windows and viewed individually, have also not been examined extensively in this application.

## Risks

For each of the sessions, the principal risk to you is minor eyestrain and fatigue associated with working on a computer and using handheld devices.

**Compensation**
Internal participants will receive a remuneration of $22.36, and external participants will receive a remuneration of $40.20 as well as travel costs to an amount equivalent to the cost of round-trip TTC fare based on the DRDC Toronto's Experimental Compensation Calculator.

**Contact Information**

Principal Investigator:

Dr. Ming Hou, Phone: 416-635-2063, Email: Ming.Hou@drdc-rddc.gc.ca

Chair, DRDC Human Research Ethics Committee (HREC):

Dr. Jack P. Landolt, Phone: 416-635-2120, Email: Jack.Landolt@drdc-rddc.gc.ca

# Annex C Consent Form

**VOLUNTARY CONSENT FORM FOR HUMAN SUBJECT PARTICIPATION**

**Protocol Number: #L-680**

**Research Project Title:** Comparison between Touch Screen and Tactile Interfaces on Performance of Virtual Unmanned Aerial Vehicle Operation

**Principal Investigator:** Dr. Ming Hou (DRDC Toronto)

**Run Director(s):** Sheila Young and Andrew Sun

I,_________________(name) of _______________________________________(address and phone number) hereby volunteer to participate as a subject in the study "Comparison between Touch Screen and Tactile Interfaces on Performance of Virtual Unmanned Aerial Vehicle Operation" (Protocol L-680). I have read the information letter and have had the opportunity to ask questions of the Investigator(s). All of my questions concerning this study have been fully answered to my satisfaction. However, I may obtain additional information about the research project and have any questions about this study answered by contacting Dr. Ming Hou at 416-635-2063 or Dr. Jack Landolt at 416-635-2000 Extension 2120.

I have been told that I will be asked to participate in six sessions with the first session being approximately 60 minutes in duration and each of the remaining five sessions being approximately 15 minutes in duration with short breaks in-between for a total of 3 hours. I will fly through simulated urban terrain using different input methods and devices. My task will be to navigate the vehicle and at one point identify a target character.

I have been told that the experimental data concerning me will be treated as **Protected A** as appropriate, and not revealed to anyone other than the DRDC-affiliated Investigator(s) or external investigators from the sponsoring agency without my consent except as data unidentified as to source.

I have been told that the principal risks of the research protocol are minor eyestrain and fatigue associated with working on a computer and using handheld devices. Also, I acknowledge that my participation in this study, or indeed any research, may involve risks that are currently unforeseen by DRDC Toronto. For Canadian Forces (CF) members only: I understand that I am considered to be on duty for disciplinary, administrative and Pension Act purposes during my participation in this experiment. This duty status has no effect on my right to withdraw from the experiment at any time I wish and I understand that no action will be taken against me for exercising this right. Furthermore, I understand that if my participation in this study results in a medical condition rendering me unfit for service, I may be released from the CF.

I understand that my name will not be identified or attached in any manner to any publication arising from this study. Moreover, I understand that the experimental data may be reviewed by an internal or external audit committee with the understanding that any summary information resulting from such a review will not identify me personally.

I understand that I am free to refuse to participate and may withdraw my consent without prejudice or hard feelings at any time. Should I withdraw my consent, my participation as a subject will cease immediately. I also understand that the Investigator(s), or their designate responsible for the research project may terminate my participation at any time, regardless of my wishes.

I have been informed that the research findings resulting from my participation in this research project may be used for commercial purposes.

I understand that as a CF member or civilian government employee participating in this research project during work hours, I am entitled to a remuneration in the form of a stress allowance for each completed session for a total amount of $22.36 if I complete the entire research project as set out in the protocol. I understand that as a non-government civilian or civilian government employee participating in this research project during non-work hours, I am entitled to remuneration that incorporates an allowance for both stress and my commitment of time for each completed session for a total amount of $40.20 as well as travel costs to an amount equivalent to the cost of round-trip TTC fare if I complete the entire research project as set out in the protocol. I also understand that I am entitled to partial remuneration if I do not complete all of the sessions. Stress remuneration is taxable. My Social Insurance Number (SIN) is required for remuneration. T4A slips are issued only for amounts combined and in excess of $500.00 remuneration per year.

I have informed the Principal Investigator that I am currently a subject in the following other DRDC research project(s):______________________________(volunteer to cite Protocol Number(s) and associated Principal Investigator(s)), and that I am participating as a subject in the following research project(s) at institutions other than DRDC:_____________ (volunteers to cite name(s) of institution(s))

<u>Secondary Use of Data:</u> I understand that my data from this study may be used in unidentified form in future related studies provided review and approval have been given by DRDC Human Research Ethics Committee.

I understand that by signing this consent form I have not waived any legal rights I may have as a result of any harm to me occasioned by my participation in this research project beyond the risks I have assumed. Also, I understand that I will be given a copy of this consent form so that I may contact any of the individuals mentioned below at some time in the future should that be required.

Volunteer's Name:_______________________________________________.

Signature:________________________________.Date:_________________.

Name of Witness to Signature:______________________________________.

Signature:_________________________.Date:_________________________.

Section Head/Commanding Officer's Signature (see Notes below):

_________________________________.Date:_________________________.

Commanding Officer's Unit: ________________________________________.

Contract Manager's Signature (see Notes below):

_________________________________.Date:_________________________.

Principal Investigator:______________________________________________.

Signature:________________________.Date:_________________________.

Notes:

For Canadian Forces (CF) members only: I understand that I am considered to be on duty for disciplinary, administrative and Pension Act purposes during my participation in this study and I understand that in the unlikely event that my participation in this study results in a medical condition rendering me unfit for service, I may be released from the CF and my military benefits apply. This duty status has no effect on my right to withdraw from the study at any time I wish and I understand that no action will be taken against me for exercising this right.

For Military personnel on permanent strength of CFEME: Approved in principle by Commanding Officer; however, members must still obtain their Section Head's signature designating approval to participate in this particular research project.

For other military personnel: All other military personnel must obtain their Commanding Officer's signature designating approval to participate in this research project.

For civilian employees at DRDC: Signature of Section Head of appropriate research centre is required designating that volunteer subject is considered either to be at work (________ (initials of volunteer)) or participating on their own time (__________(initials of volunteer)) and that approval has been given to participate in this research project.

For civilian contractors working at a DRDC Centre: Signature of the contract manager must be obtained indicating they are aware of the volunteer's intent to participate in this research project.

FOR SUBJECT ENQUIRY IF REQUIRED:

Should I have any questions or concerns regarding this project before, during or after participation, I understand that I am encouraged to contact the appropriate DRDC research centre cited below. This contact can be made by surface mail at this address or by phone or email to any of the DRDC numbers and addresses of individuals listed below:

**Defence R&D Canada-Toronto**
1133 Sheppard Avenue West
PO Box 2000
Toronto, Ontario, M3M 3B9

Principal Investigator or Principal DRDC Investigator:

Dr. Ming Hou, DRDC Toronto, 416-635-2063, Ming.Hou@drdc-rddc.gc.ca

Chair, DRDC Human Research Ethics Committee (HREC):

Dr. Jack P. Landolt, DRDC Toronto, 416-635-2120, Jack.Landolt@drdc-rddc.gc.ca

# Annex D Participant Background Questionnaire

Participant #: _____ Group #: _____ Administrator: _______________ Trainer: _______________

The following information will only be retained for the purposes of this study, and will not be disclosed to any other individual or organization.

Please circle the appropriate responses:

1. **Age:** ________
2. **Gender:** Male or Female
3. **Have you ever had experience in Unmanned Vehicle (e.g., Call of Duty, Remote Control toys, etc.) control?** Yes or No

   If Yes, please indicate approximately the number of hours of experience:

   Less than 29 hours 30-49 hours 50-99 hours More than 100 hours
4. **Have you ever played video games?** Yes or No

   If Yes, please indicate approximately the number of hours played in total:

   < 29 hours 30-49 hours 50-99 hours > 100 hours

   Please list console(s): ______________________________________________
5. **Have you ever had experience with Touch Screen interfaces?** Yes or No

   If Yes, please indicate approximately the number of hours of experience:

   < 29 hours 30-49 hours 50-99 hours > 100 hours
6. **Have you ever had experience with Button Control interfaces?** Yes or No

   If Yes, please indicate approximately the number of hours of experience:

   < 29 hours 30-49 hours 50-99 hours > 100 hours
7. **Have you ever had experience with handheld devices?** Yes or No

   If Yes, please indicate approximately the number of hours of experience:

   < 29 hours 30-49 hours 50-99 hours > 100 hours

   Please list device(s): ________________________________________________

---------------------------------------Training Admin Section-------------------------------------

G1: PC________; To-Si________; Ta-Si________; To-Se________; Ta-Se________;

G2: PC________; Ta-Si________; To-Se________; Ta-Se________; To-Si________;

G3: PC________; To-Se________; Ta-Se________; To-Si________; Ta-Si________;

G4: PC________; Ta-Se________; To-Si________; Ta-Si________; To-Se________;

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# Annex E Subjective Measure Rating Form

### Workload Measure

As noted above in the protocol, a form will be used to obtain objective measures of workload. Subjective ratings in the form of a modified NASA TLX [3] 10 scale will be used. These rating forms will be tuned for each participant and for each of the participant's critical tasks. Note –because of the relatively small sample size in this experiment, analyses of cross- and inter-correlations are not justified and paired comparisons will not be performed.

Instructions: Read and understand the Rating Scale Definitions table below. Then use the rating scale on page 20 to mark your results.

| **RATING SCALE DEFINITIONS** | | |
|---|---|---|
| Title | Endpoints | Descriptions |
| | | |
| MENTAL DEMAND | *Low/High* | How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving? |
| PHYSICAL DEMAND | *Low/High* | How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious? |
| TEMPORAL DEMAND | *Low/High* | How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic? |
| EFFORT | *Low/High* | How hard did you have to work (mentally and physically) to accomplish your level of performance? |
| PERFORMANCE | *Good/Poor* | How successful do you think you were in accomplishing the goals of the task set by the experiment administrator (or yourself)? How satisfied were you with your performance in accomplishing these goals? |
| FRUSTRATION LEVEL | *Low/High* | How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task? |

**Instructions:** Using the rating scales below and the definitions provided, mark each scale to indicate the degree of workload you experienced while completing the indicated task. Take note that with the exclusion of the performance scale the ratings are low to high, where as the performance scale is good to poor.

**Task:** Establish the EA-MAV in a position inside of the target building to allow the operator to view a non-playable target character.

**MENTAL DEMAND**

Low 1 3 5 7 9 High

**PHYSICAL DEMAND**

Low 1 3 5 7 9 High

**TEMPORAL DEMAND**

Low 1 3 5 7 9 High

**EFFORT**

Low 1 3 5 7 9 High

**PERFORMANCE**

Good 1 3 5 7 9 Poor

**FRUSTRATION**

Low 1 3 5 7 9 High

# Annex F  Situational Awareness Measure Questionnaire

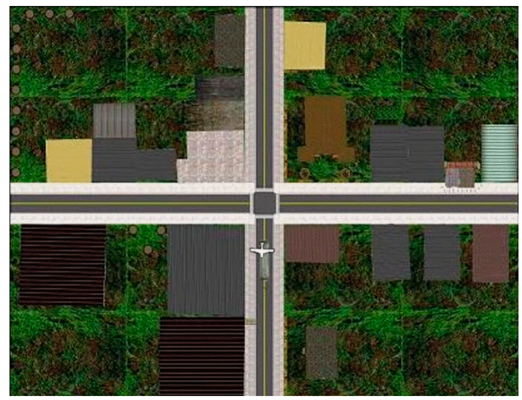
As noted above in the protocol, a questionnaire will be used to obtain objective measures of situational awareness.  Two questions regarding the relative location and the image viewed from the video sensor at that moment would be asked.

==========================================================================

1. Which image closely represents the current location of the EA-MAV on the map, i.e. the location on the map, at the time the mission is paused?  Please only circle one image's corresponding letter.

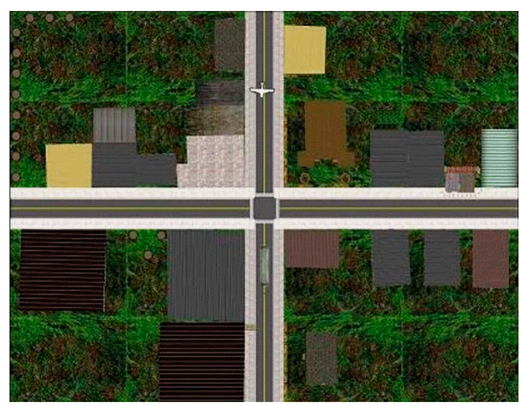
a.

c.



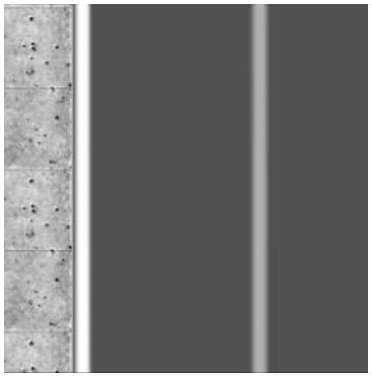
b.

d.



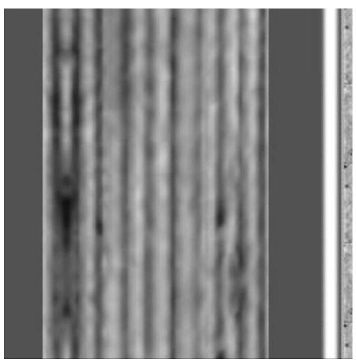
2. Which image closely represents the current image from the sensor of the EA-MAV, i.e. the sensor view, at the time the mission is paused? Please only circle one image's corresponding letter.

a.

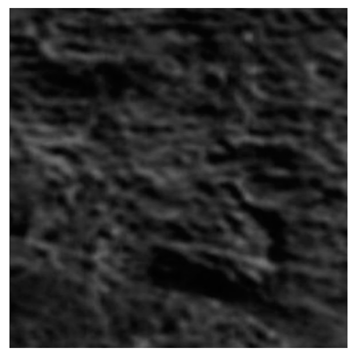


c.

b.



d.



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# Acronyms and initialisms

| | |
|---|---|
| ANOVA | Analysis of Variance |
| CF | Canadian Forces |
| DRDC | Defence Research & Development Canada |
| EA-MAV | Extremely Agile Micro Aerial Vehicle |
| GCS | Ground Control Station |
| GUI | Graphical User Interface |
| MAV | Micro Aerial Vehicle |
| NASA | National Aeronautics and Space Administration |
| NPTC | Non-playable Target Character |
| PC | Personal Computer |
| PDA | Personal Digital Assistant |
| R&D | Research & Development |
| SAGAT | Situational Awareness Global Assessment Technique |
| TLX | Task Load Index |
| UAV | Unmanned Aerial Vehicle |
| UMPC | Ultra Mobile Personal Computer |
| UV | Unmanned Vehicle |
| VNCEP | Virtual Navigation and Collaboration Experimentation Platform |
| DND | Department of National Defence |
| DRDC | Defence Research & Development Canada |
| DRDKIM | Director Research and Development Knowledge and Information Management |
| R&D | Research & Development |

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(U) The use of Extremely Agile Micro Aerial Vehicles (EA−MAVs) drives the need for a small and light controller which will not hinder a soldier carrying it. This requirement brings an issue of designing an effective operator interface coupled with the controller. Little human factors work has been done on what the most effective method is for controlling EA−MAVs using a handheld device. To investigate design methods for the development of an interface which must be intuitive in function and easy to learn for an average soldier, DRDC Toronto conducted an experiment to evaluate interface display mode and command control input method. Display mode compared a display that showed both a sensor view and a map view (simultaneous) with a display that showed one view at a time (sequential). Command control input method compared two types of input control methods: touch screen and tactile buttons. Forty four (44) subjects participated in the experiment and navigated a virtual EA−MAV through specified way−points in an urban area and a building. Subjects' performance was measured against six dependent variables: (1) situation awareness, (2) display switch frequency (between sensor view and map view), (3) task completion time, (4) mental workload, (5) trajectory error of the flight, and (6) training time. The results revealed that the simultaneous display and the touch screen control are the optimal design methods for the handheld interface to be used easily when maintaining situation awareness. The findings provided guidance for designing operator interfaces on handheld devices and further facilitated the development of a statement of requirements of EA−MAV systems

(U) L'emploi des Extrêmement agile Micro Aerial Vehicules (EA−MAVs) entraîne la nécessité de développer un instrument de contrôle petit et léger qui n'empêcherait pas les soldats qui l'utilise. Cet exigence porte un problème avec la conception d'un interface opérateur efficace pour l'intégration avec l'instrument de contrôle. Il n'y a pas beaucoup de recherche dans le domaine des facteurs humains qui mettre au point le méthode le plus efficace pour contrôler un EA−MAV en utilisant un appareil portatif. Pour examiner les méthodes de conception pour le développement d'un interface avec un fonctionnement intuitif et qui est facile pour la moyenne des soldats à apprendre, RDDC Toronto a mené une expérience pour évaluer de modes d'affichage et de méthodes de contrôle d'entrée. Le mode d'affichage a comparé un affichage combiné en vue de capteurs et vue sur la carte (simultanée), avec un écran qui sépare les deux points de vue (séquentiel). Le méthode de contrôle d'entrée a comparé un écran tactile avec des boutons tactiles. Quarante quatre (44) sujets ont participé à l'expérience, où ils ont navigué un EA−MAV virtuel par un chemin spécifié dans un espace urbain et un bâtiment. Les six variables dépendantes mesurées de la performance des sujets ont été (1) conscience de la situation (2) la fréquence de commutation d'affichage (entre la vue du capteur et la carte), (3) le temps d'exécution des tâches, (4) charge de travail mental, (5) erreur de trajectoire du vol, et (6) le temps de formation. Les résultats ont révélé que l'affichage simultané et l'écran tactile de contrôle sont les conditions les plus avantageuses en concernant la facilité d'usage en conservant conscience de la situation pour l'interface portatif. Les conclusions a fourni des orientations pour la conception d'un interface opérateur à utiliser en conservant conscience de la situation. Ces résultats fournissent un guide pour la conception d'interface d'operateur dans dispositifs portables and a facilité le développement des conditions des systèmes d' EA−MAV.

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(U) micro aerial vehicle; unmanned vehicle; remotely operated vehicle; operator interface; interface design; handheld device; mobile computer; display format; simultaneous display; sequential display; command input method; tactile button, touch screen; measure of effectiveness; measure of performance; situation awareness; workload

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